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Evaluation of Incident Management Strategies

FINAL REPORT

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16. Abstract

In this project, incident management related literature is reviewed and important incident management procedures and technologies currently used in the US are described in detail. Impacts of these incident management strategies and technologies in terms of measures of effectiveness are also discussed using the information obtained from the literature review. Accident data are obtained from NJDOT and part of this data related to the proposed test network, namely part of South Jersey network, is analyzed to understand the incident occurrence characteristics. Several incident occurrence\incident duration and severity models are also proposed. Comprehensive user-friendly "incident management" simulation software is developed as part of this project. This was needed in order to realistically evaluate the benefits of various incident management strategies and technologies identified in the literature review section. Rutgers Incident Management Systems (RIMS) software uses a realistic traffic simulation model based on the cell transmission model proposed by Daganzo [35]. The developed software can also generate incidents and test various response strategies and technologies. This integrated incident management and traffic simulation tool which is an attempt to develop a specific tool just designed for the purpose of incident management evaluation studies, is then applied to the selected test network using various scenarios ranging from simple to more complex. Finally, a detailed cost benefit analysis for these selected scenarios using the cost figures mainly obtained from the cost database provided by FHWA. The Cost Benefit analysis produced C/B ratios higher than for all the tested scenarios, implying positive impacts of the tested incident management scenarios and technologies. Our positive findings are also shown to support the findings of similar studies conducted in other parts of the country. However, it should be kept in mind that these are preliminary results based on various assumptions and more detailed studies are needed to further improve the reliability of these results.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

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INTRODUCTION

Background

Incidents can be categorized as accidents, vehicle breakdowns, spilled loads or any other events that reduce the roadway capacity. Incidents lead to congestion when the traffic demand exceeds the reduced roadway capacity at the incident location [(1)]. Nationally, highway incidents account for approximately 60 percent of vehicle-hours lost to congestion [(2)]. Therefore, quick detection, response, and removal of incidents are essential to maximizing the efficiency of the existing traffic networks. It is now widely accepted that these non-recurrent congestion problems can be reduced by the proper use of incident management procedures.

"Incident management is defined as the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of incidents, and improve the safety of motorists, crash victims, and incident responders. These resources are also used to increase the operating efficiency, safety, and mobility of the highway by systematically reducing the time to detect and verify an incident occurrence, implementing the appropriate response, and safely clearing the incident, while managing the affected flow until full capacity is restored." [(2)]

The incident management process can be characterized as a set of activities that fall into the following seven categories. The following sections briefly describe these categories.

<u>Incident Detection</u>

Incident detection is the process by which an incident is first identified by the agencies involved in incident management. It is a two-step process of determining the presence and location of an incident. First, the existence of non-recurrent congestion is determined using data obtained via various surveillance systems deployed or via information received from travelers. Then, the data are analyzed to determine if the cause of the congestion is actually an incident. Generally, incident detection is the responsibility of the local agencies and it depeneds on available resources in the area. The methods commonly used to detect and verify incidents include:

- Mobile telephone calls from motorists
- Closed circuit TV cameras viewed by operators (CCTVs)
- Electronic traffic measuring devices (e.g., video imaging, loop or radar detectors)
- Automatic vehicle identification (AVI) combined with detection software
- Motorist aid telephones or call boxes
- Police patrols
- Aerial surveillance
- Department of transportation or public works crews reporting via two-way radio
- Service patrols

<u>Incident Verification</u>

Incident verification can be defined as the confirmation of the incident's exact location, and the relevant details. Verification step includes gathering enough information to dispatch the proper initial response. Incident verification is usually completed with the arrival of the first responders on the scene. However, when hazardous materials are involved, the verification process may be quite extensive. The methods of incident verification include the following:

- Closed circuit TV cameras viewed by operators
- Dispatch field units (e.g., police or service patrols) to the incident site
- Communications with aircraft operated by the police, the media, or an information service provider
- Combining information from multiple cellular phone calls

Motorist Information

Motorist information involves activating various means of disseminating incident-related information to affected motorists. Media used to disseminate motorist information includes the following:

- Commercial radio broadcasts
- Highway advisory radio (HAR)
- Variable message signs (VMS)
- Telephone information systems
- In-vehicle or personal data assistant information or route guidance systems
- Commercial and public television traffic reports
- Internet/on-line services
- A variety of dissemination mechanisms provided by information service providers

Motorist information needs to be disseminated as soon as possible and beyond the time it takes clear an incident. In fact, it should be disseminated until traffic flow is returned to normal conditions. This may take hours if an incident occurs during a peak period and has regional impacts.

Incident Response

Incident response is the activation of a planned strategy for the safe and rapid deployment of the most appropriate personnel and resources to the scene. Information management plays an important role by providing the necessary details to the appropriate response personnel.

Incident response includes dispatching the appropriate personnel and equipment and activating the appropriate communication links and motorist information media as soon as there is reasonable certainty that an incident has occurred. A quick incident response requires alertness of each responding agency or service provider. This is maintained ready through training and planning, both individually and collectively with other response agencies. Effective response mainly involves a number of agencies (i.e., planned cooperatively) for a variety of incident types, so that response to individual incidents is coordinated, efficient, and effective. Some of the incident response resources are as follows:

- Computer-Aided Dispatch (CAD)
- Service Patrol Fleets
- Towing and Recovery Vehicles
- Law Enforcement Fleets
- Fire Engines
- Rescue Units/Ambulances
- Major Incident Response Teams
- Changeable Message Signs (CMS)
- HAZMAT Response Units
- Arterial Signal Control

Site Management

Site management is the process of effectively coordinating and managing on-scene resources to remove the incident and reduce the impact on traffic flow. Ensuring the safety of response personnel, incident victims, and other motorists is the foremost objective of incident site management. Site management encompasses the following activities:

- Accurately assessing incidents
- Properly establishing priorities
- Notifying and coordinating with the appropriate agencies and organizations
- Using effective liaisons with other responders
- Maintaining clear communications

Effective incident site management can be facilitated by an incident command system (ICS). An ICS is a formalized system that maintains consistency in the way agencies and service providers function cooperatively at an incident scene. ICS maintains efficiency by eliminating the need to develop separate response plans at each incident. Components of an ICS include:

- Common terminology
- Modular organization
- Integrated communications

- Agreed upon command structure
- Consolidated action plans
- Manageable span of control
- Designation of incident facilities
- Comprehensive resource management

Traffic Management

Traffic management involves the application of traffic control measures in areas affected by an incident. Traffic management in the context of an incident may include:

- Establishing point traffic control on-scene
- Managing the roadway space (opening and closing lanes, blocking only the portion of the incident scene that is needed for safety, staging and parking emergency vehicles and equipment to minimize impact on traffic flow)
- Deploying appropriate personnel to assist in traffic management (e.g., state police, local police, and service patrols)
- Actively managing traffic control devices (including ramp meters, lane control signs, and traffic signals) in affected areas, and
- Designating, developing, and operating alternate routes.

Incident Clearance

Incident clearance is the process of removing wreckage, debris, or any other element that disrupts the normal flow of traffic or forces lane closures, and restoring the roadway capacity to its pre-incident condition. This may also include temporary or permanent repair to the infrastructure.

Incident clearance is typically the most time-consuming step in the incident management process - at least twice the duration of other steps in the process. It is a multi-agency process with a single objective under the incident command structure approach - to safely remove roadway obstructions and restore the flow of traffic.

As presented in Figure 1, the major phases involved in incident management occur sequentially. The figure presents the temporal distribution of the phases and describes the key time steps during the incident management process. As can be seen from the figure, on-scene traffic management (which involves site management and traffic management) and motorist information dissemination commences during the incident response phase and continues throughout the incident impact period. These phases are explained in detail in the following sections.

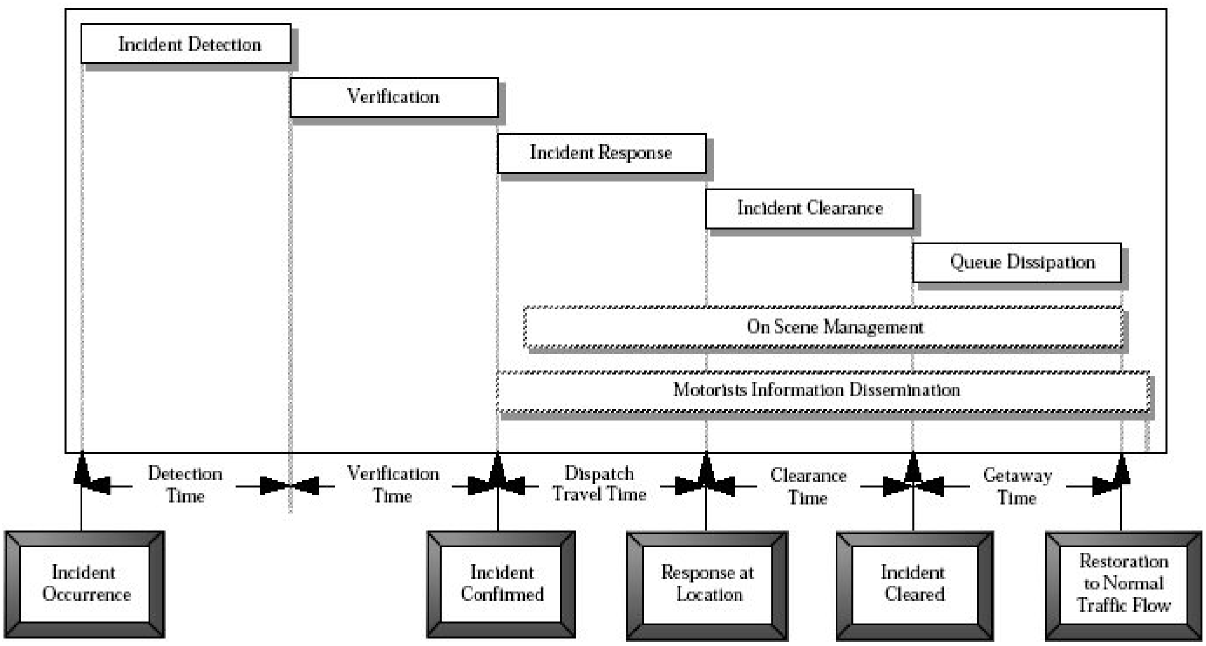

Figure 1. Temporal distributions of incident management phases [(3)]

Incident Delays

The effect of an incident on the traffic is illustrated in Figure 2. Horizontal axis represents the time, and the vertical axis represents traffic volume (arrivals and departures). The slope of these lines represents the traffic-flow rate. When an incident occurs, the actual traffic flow after the incident location decreases due to the reduction of the roadway capacity. As soon as the incident is cleared, the traffic flow is higher than regular demand due to the vehicles waiting behind the incident site. However, the traffic flow is constrained by the maximum capacity of the roadway at the incident location. If the traffic before the incident site is diverted to alternative routes delays are expected to reduce due to lower traffic demand. This delay reduction due to traffic diversion is shown by the dotted area in Figure 2.

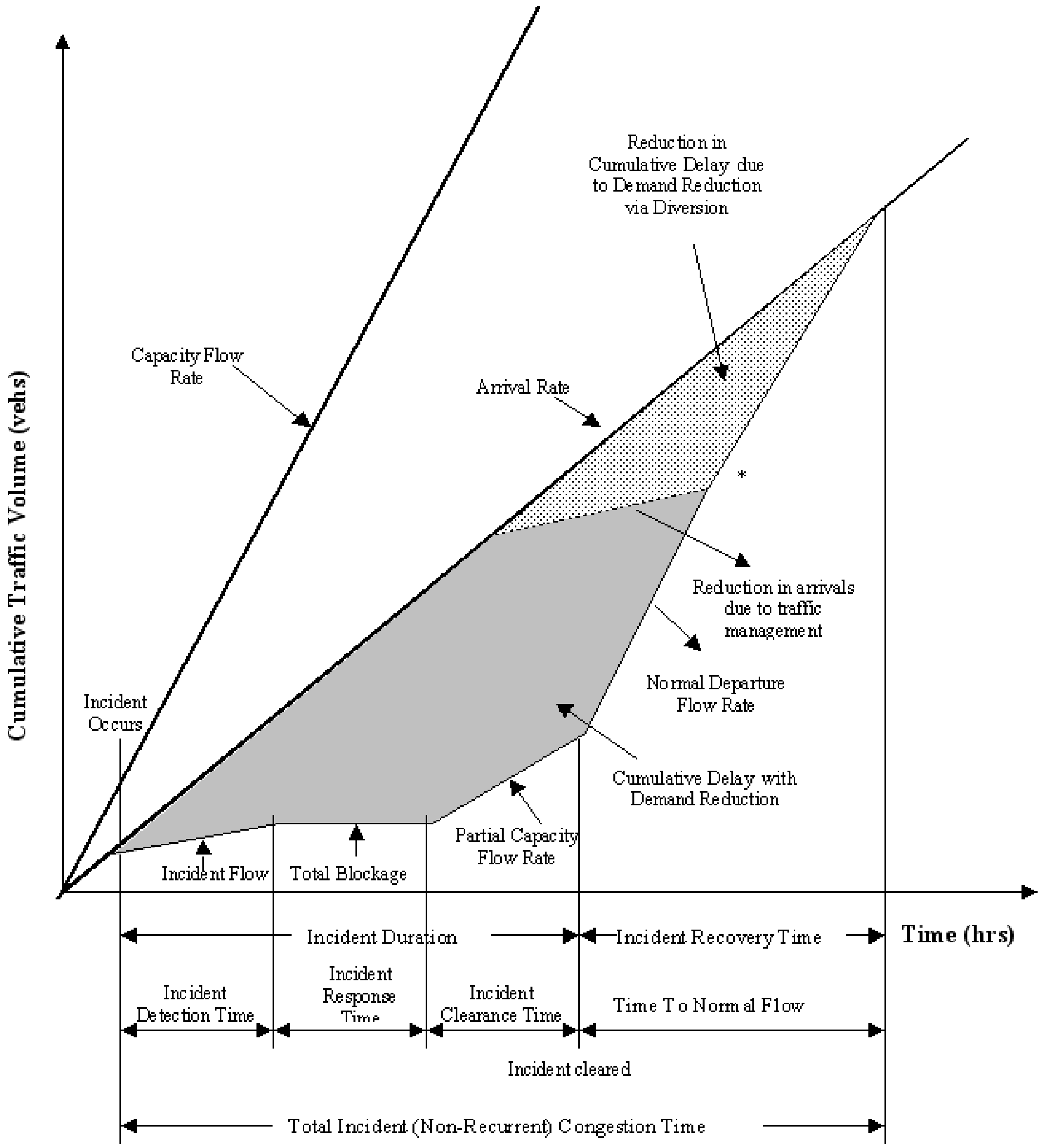

Figure 2. Total delay due to an incident [4]

* This line is a straight line, which is parallel to the “Capacity Flow Rate” line.

Breakdown of Incident Duration

As shown in Figure 1, the overall duration of an incident, from beginning to end, can be divided into several smaller periods that are briefly defined below:

(1) Detection Time (t_n): This is the time measured from the incident occurrence until the time that related agencies are informed. Incident characteristics, such as the type of the incident and its location and severity are identified within the detection time..

(2) Dispatch Time (t_d): This is the time between the notification of the response units about the incident and the assignment of the most appropriate emergency vehicle. If a service vehicle is available, then t_d = 0. Otherwise, t_d equals to the waiting time until a service vehicle becomes available. Dispatch time will clearly be affected by the type of the dispatching policy, the number of available emergency vehicles and the prevailing traffic conditions, etc.

(3) Travel Time (t_t): This is the elapsed time between the allocation of service vehicles and the arrival of the service vehicles at the incident site. Travel time depends on the traffic conditions, and the distance between the assigned emergency service location and the incident location..

(4) Clearance Time (t_c): This is the time between the arrival of the emergency vehicles and the time the incident is fully cleared. Depending on the incident attributes, clearance time can be divided into on-scene time and removal time.

It is apparent that any reduction in detection, response, and clearance time reduces the total incident duration.

Incident Response Operations

Dispatching emergency vehicles

Traffic Flow Restoration Unit (TFRU) is used as a general term to describe emergency units that respond to and clear incidents. A TFRU may consist of a single vehicle, i.e., tow-truck, or it may be a multi-vehicle unit including towtrucks, ambulances, fire trucks, emergency medical service (EMS) and so forth. For simplification, it is assumed that the clearance process of an incident cannot be interrupted. Therefore, a TFRU becomes unavailable to other incidents when it is already engaged with an incident. One incident response approach is to dispatch TFRUs from the depot. At anytime, if there are more than one incident on the waiting list, the incident to be serviced is determined by the dispatching policy. Generally speaking, TFRU dispatching policy can be categorized into two types based on the incident attributes, including occurrence time, location and severity.

(1) First come, first serve (FCFS). This policy dispatches the TFRU to the incident, which occurs first. Two disadvantages characterize the FCFS policy. The first disadvantage is the time spent by traveling long distances, which causes excessive delay for an incident. Secondly, sites with demand for services that are on TFRU's path may be ignored by the TFRU, which is assigned to an incident that occurred first at a farther location.

(2) Nearest neighbor (NN). This policy dispatches the TFRU to the nearest incident. The NN policy seems to result in less waiting time for service under high workloads because it dispatches the TFRU to the closest location with a need for assistance, regardless of the time of incident occurrence.

The factors that play a major role in the effectiveness of any incident response approach are (1) the choice of depot locations, (2) TFRU allocation strategy, and (3) the dispatching policy

Freeway service patrol (FSP)

The use of freeway service (or motorist assistance) patrols (FSP) is another way to facilitate the removal of incidents through fast response and clearance times. FSP team consists of tow-trucks that patrol certain freeway segments during commute hours, and provide assistance to disabled vehicles. They are able to handle a large number of minor incidents (stalls, flat tires, out of gas, and minor accidents) that constitute the largest portion of all freeway incidents. FSP serve also as a detection and verification mechanism for major incidents by providing information to transportation management centers. Benefits of FSP include reduction in incident related delay, fuel consumption and vehicle emissions. They also assist law enforcement agencies by reducing the amount of time that police officers spend on non-enforcement activities. The use of freeway service patrols to handle incidents has grown substantially over the past decade. Over 70 freeway service patrol programs operate around the country with 45 programs initiated since 1992. The majority of these are funded and run by the state DOTs and are highly cost effective. Of the 49 Metro areas in the US with populations over one million, only four do not have a freeway service patrol operating. Table 1 summarizes some of these programs.

Table 1. Summary of some FSP programs

Source: MN/DOT FAQ – Freeway Incident ReSponse Team (FIRST)

City	Annual Cost ($ million)	Miles Covered	# Vehicles	Benefit/Cost*
Los Angeles, CA	$ 21.3	411	146 tow trucks	15:1
San Francisco Bay Area, CA	$ 6.0	362	60 tow trucks	11:1
San Diego, CA	$ 2.4	203	26 tow trucks	7:1
Chicago, IL	$ 5.5	80	35 tow trucks	17:1
Houston, TX	$ 1.4	190	18 vans	6.6:1 to 23:1
Denver, CO	$ 1.3	60	12 tow trucks	20:1 to 23:1
Minneapolis/St. Paul, MN	$ 1.0	170	8 pickup trucks	4:1

According to a California PATH Research Report (1), the average response time of FSP tow trucks was 10.8 minutes, and the incident response times (and durations) without FSP were higher by about 7 to 20 minutes on average. It was observed that in order to achieve a reduction of 15 minutes in incident duration by the use of FSP the benefit/cost ratio needed to be greater than 5:1.

To improve the cost efficiency of the FSP service, the optimal value of the length and the location of the patrolling route and the number of patrolling vehicles have to be determined.

INCIDENT MANAGEMENT RELATED PROGRAMS IN NEW JERSEY

New Jersey Department of Transportation (NJDOT) has implemented a statewide incident management program that provides incident management training to emergency responders and improves the identification of, response to, and clearance of incidents on the interstates and major arterials. It has established a fleet of vans to patrol the major commuting routes in North and South Jersey during the AM and PM peak periods. These vans are equipped to handle minor auto repairs, push disabled vehicles from the travel lanes and serve as support for major incidents. The drivers of the van are trained in first aid, CPR, and minor auto repair. Following are some of the incident management programs implemented in New Jersey.

"MAGIC"

During 2000, NJDOT activated the $45 million "MAGIC" intelligent transportation system along the New Jersey Turnpike and other North Jersey roadways. The "MAGIC" system, which stands for Metropolitan Area Guidance Information and Control, uses radar, pavement sensors, electronic message signs, fiber-optic cable, and closed circuit cameras to alert drivers to traffic accidents or weather hazards and to post the best alternate routes.

The "MAGIC" project along I-80 is an estimated $100+ million improvement to the corridor. The system employs detectors, cameras, message signs, etc., to deliver real-time information to motorists about congested or emergency locations and recommend alternate routing. MAGIC also employs Highway Advisory Radio (HAR). Future phases of the MAGIC program are being conceptualized.

New Jersey Turnpike Authority

The Authority uses a network of loops (900+), cameras, and VMS to manage traffic operations on the Turnpike. An operations center monitors a graphic display of the system, dispatches service (to more than 93,000 disabled vehicles last year), and communicates with more than 200 changeable message signs and other devices over radio links using a universal protocol. Other devices in use include eleven HAR sites, a #95 cell phone incident reporting number, and weather sensors. Electronic toll collection is planned to be in full operation at all turnpike interchanges by May 2000. The Turnpike Authority uses federal funding to pay for the following enhancements to their system:

- Nine Variable Message signs
- Weather surveillance stations
- CCTV cameras located at Turnpike exit 16W

The Turnpike Authority and the New Jersey State Police also receive federal funding for the development of a computer aided dispatch and electronic records management system.

I-95 Corridor Coalition

The I-95 Corridor Coalition is an alliance of transportation agencies, toll authorities, and related organizations, including law enforcement, from the State of Maine to the State of Florida, with an affiliate member in Canada. New Jersey is also a member state of this coalition [18]. The Coalition began in the early 1990's as an informal group of transportation professionals working together to more effectively manage major highway incidents that impacted travel across jurisdictional boundaries. In 1993, the Coalition was formally established to enhance transportation mobility, safety, and efficiency in the region. The Coalition provides a forum for key decision and policy makers to address transportation management and operations issues of common interest. This volunteer, consensus-driven organization enables its myriad state, local, and regional member agencies to work together to improve transportation system performance. Commuters can obtain valuable information like traffic delays and construction activities in their respective areas by logging on to the website of this coalition. Facilitation of regional incident management in areas such as pre-planning, coordination and communication among transportation and public safety agencies in the corridor remains a key part of the Coalition's focus.

A series of steps were also taken to improve highway safety in New Jersey, including improved travel information for highway users in the state. (15) Following is a brief description of these steps:

- **Variable Message Signs (VMS)** – VMS are mobile units that can import real time information and flash traffic warnings and safety messages that are highly visible to interstate drivers. VMSs are deployed throughout the state of New Jersey, for example, on route 295, route 130, etc.
- **Pilot Vehicle Crossover Barrier Program** - NJDOT has installed barriers at two locations, on I-78 in Whitehouse Station and on I-80 in Roxbury Township, to examine their ability to minimize damage during an accident. These barriers are meant to prevent a vehicle from crossing over into oncoming traffic at the time of collision.
- **Expand Emergency Service Patrol (ESP)** - In coordination with the State Police, NJDOT has increased the scope of its ESP. ESP units coordinate local authorities and emergency services when a traffic incident occurs. This has helped in reducing congestion by reducing vehicle hours of delay, a critical performance measure. The ESP team currently aids more than 13,000 drivers annually and its service includes stretches of I-78. Presently, incidents include a variety of non-recurring events, such as flat tires, abandonment, fuel outage, breakdown or debris. Often, incidents cause delays because vehicles remain in the traveling lanes or in a position where the traveling public must reduce speed or stop to avoid the cause of the incident. Increased ESP activity that removes the cause of such incidents more rapidly allows traffic to resume a freer flow. With the number of incidents responded to by ESP averaging over 1000 per month (19) for the Northern Region of New Jersey, its evident that the program is gaining momentum.

- **Safe Driving Distances Signs** - NJDOT has installed signs along interstates reminding drivers to maintain a safe distance between themselves and the vehicles in front of them.
- **Public Service Announcements (PSA) -** NJDOT has also designed PSAs that promote courtesy on the roads, reminding drivers of safety practices and encouraging them to report erratic and aggressive driving to the State Police hotline.
- **Public Education Campaign** - The Department of Education and the Department of Transportation are working with the New Jersey Motor Truck Association and USDOT's Motor Carrier's Association to expand the "Share the Road Program". The "Share the Road Program" brings truck drivers to driver's education classes to educate students about "No-Zone" blind spots and safe interaction on the highway.
- **Real Time traffic alerts** - NJDOT has added real time traffic information and CCTV pictures on major New Jersey routes to its web sites. These links help the commuters in planning their trips accordingly and avoid traffic delays.

NJDOT - Traffic Operations South

NJDOT Traffic Operations South is responsible for southern New Jersey's transportation network, which includes Mercer, Monmouth, Burlington, Ocean, Camden, Gloucester, Atlantic, Salem, Cumberland, and Cape May counties. The agency uses a variety of sensors to collect traffic data, including loop detectors, VIDS, cameras, and their own service patrol. As of the interview date, all sensory equipment, except for the VIDS, was operational. NJDOT South's service patrol is by far the most wide-ranging means to collect traffic data. The service patrol consists of eleven trucks, six of which cover southern New Jersey, while the remaining trucks cover central New Jersey. The trucks are operational for 16 hours/day for 5 days/week. Each group of trucks, i.e. the central and southern group, reports to a supervisor who collects incident data and stores it in a database. The loop detectors and video cameras are operational 24 hours/day for 7 days/week. Usually, these devices are deployed in pairs in order to provide reliability and redundancy in the data collection and analysis process. Data is transmitted from these devices to the traffic operation center (TOC) through fiber optic lines and T1 lines, and the data collected by the loop detectors is stored at an aggregation level of 5-15 minutes. The video cameras all have pan, tilt, and zoom capabilities. Traffic Operations South also employs weather sensors to collect precipitation data. Currently, there are twelve weather sensors in the field, and they collect data concerning precipitation type (rain, snow, ice), atmospheric data (wind speed), and temperature data (atmospheric and pavement temperatures). Traffic Operations South does not operate weight stations or ETC.

NJDOT South collects various types of traffic information useful for ATIS operations in New Jersey such as incident data and special event data. The agency also generates and disseminates traffic advisory information, and provides other public and private agencies with any required traffic data. NJDOT South has also established relations with a traffic information ISP (Information Service Provider), SmartRoute Systems. As a result of this relationship, NJDOT South passes their traffic information onto SmartRoute for public dissemination, while SmartRoute passes traffic data collected by their own traffic sensors to NJDOT South. Furthermore, NJDOT South promotes information sharing by taking part in the Information Exchange Network (IEN). The IEN was designed to facilitate communications and information sharing among I-95 Coalition member agencies and with private entities. This shared information supports transportation management and traveler information on a regional (Maine to Virginia) and corridor wide (in this case, the I-95 Corridor) basis.

NJDOT - Traffic Operations North [20]

NJDOT North is located in Mount Arlington, New Jersey. This Traffic Operations Center is responsible for all state roadways in northern New Jersey, including roadways in Middlesex, Somerset, Hunterdon, Warren, Sussex, Morris, Essex, Hudson, Union, Passaic, and Bergen counties. The agency primarily uses two types of traffic sensing equipment: pavement loops and radar. The former is currently used in various locations throughout the northern region, while radar is being installed in the Route 80 Corridor. Data from these sensors is transmitted through leased phone lines and fiber optic lines. The agency also operates at least 60 video cameras in its jurisdiction, all with pan, zoom, and tilt capabilities. At this time, data collected using traffic sensing equipment and video cameras is not stored, but future plans include data collection and aggregation. This agency does not operate any weather sensing equipment, electronic toll collection (ETC), or weigh stations.

NJDOT North collects various types of traffic information useful for advanced traveler information systems (ATIS) operations in New Jersey. Collected information includes incident data, traffic congestion data, and special event data. The agency also generates and disseminates traffic advisory information, and provides other public and private agencies with any required traffic data. This information is stored, and is available to the general public and other government agencies. Information sharing is conducted using IEN.

LITERATURE REVIEW

One of the most advanced incident management program in the US is in California. There are various reports that describe various components of this incident management program in California and its effectiveness. Skabardonis *et al.* [(1)] investigate the effectiveness of freeway service patrols on a 7.8 mile section of I-10 freeway in Los Angeles. The primary Measure of Effectiveness (MOE) selected in this study for the FSP evaluation is savings in delay. Other MOEs include savings in fuel consumption and air pollutant emissions, and benefits to the freeway systems operators (improved incident detection, response and clearance times.) They develop an evaluation methodology to derive estimates of performance measures in the absence of data for before FSP conditions. Based on the difference in average travel speeds under normal and incident conditions using probe vehicle speeds and volume data from the loop detectors, the FSP effectiveness is assessed. From the estimated benefit/cost ratio based on delay and fuel savings for a range of typical reductions in incident durations, the investigators conclude the FSP is cost effective.

Al-Deek and Kanafani [(5)] evaluate the Advanced Traveler Information Systems (ATIS) in the incident management. The study findings suggest that route guidance has a significant role in the management of incidents during the off-peak period, when uncongested alternate routes are likely to be available. During the peak period, however, the alternate routes are usually congested, and consequently there is a need to spread traffic over time rather than space. This can be achieved through departure time switching rather than route switching. Regarding incident detection, Petty et al [(6)] present an off-line approach for evaluating incident detection algorithms. Instead of focusing on determining the detection rate versus false alarm rate curve, they propose a cost benefit analysis where the cost mimics the real costs of implementing the algorithm and the benefit is in terms of the reduction in congestion. Via a detailed example, they demonstrate that this approach is more practical than the traditional one.
The prediction of incident durations can facilitate incident management and support traveler decisions. A time sequential methodology is developed by Khattak et al [(7)] to predict the incident durations as information about the incident is acquired in a Traffic Operations Center (TOC). Specific hypotheses are tested by developing truncated regression models of incident duration using data provided by the Illinois Department of Transportation (IDOT) on Chicago area freeways. The models show that incident durations are longer when the response times are higher, the incident information is not disseminated through the public media, there are severe injuries, trucks are involved in the incident, there is heavy loading in the truck, State property is damaged, and the weather is bad. The most important variables in incident duration prediction were incident characteristics and the consequent emergency response actions.

Computer simulation is a useful approach to study the incident management system. Liu and Hall [(8)] develop a simulation program (INCISIM) that simulates the occurrence of highway incidents, the dispatching of emergency vehicles, and the traffic flow on the network. INCISIM can represent multiple types of emergency vehicles that include highway patrol cars, freeway service patrol trucks, tow trucks operating from fixed bases, highway maintenance vehicles, and fire trucks. To focus on dispatching policies, INCISIM utilizes a simplified representation of the highway system. Highways are divided into a collection of sections. Users need to enter data representing the normal amount of traffic, by time of day, for each section, along with section capacity. The interdependence between congestion on nearby sections is only modeled approximately by considering interactions with downstream sections.

Ozbay and Bartin [(9)] develop a complete simulation model to evaluate the performance of the incident management strategies that involve different types of response vehicles and traffic conditions. This model was applied to a real network and real-world data and found that an additional tow truck in the system is more effective in reducing incident duration especially in the long term, especially when there is always a possibility of having a higher incident occurrence rate. Since different transportation network have different characteristics, it is not easy to generalize these results to other networks. In terms of incident response, lots of mathematical models have been introduced in the literature. Zografos et al. [(29)] proposes an analytical framework that can minimize the freeway incident delays through the optimum deployment of traffic flow restoration units (TFRU). The proposed model integrates three modules namely:

- Districting model to obtain optimal locations of vehicles that minimize the total average incident response workload per vehicle on freeways, subject to a constraint on the maximum number of available vehicles
- Simulation model that simulates traffic restoration operations
- Dynamic mesoscopic traffic simulation model (KRONOS) that estimates traffic incident delay

The model proposed by Zografos et al. [29] is shown to be an effective tool that can model and evaluate the effects of deployment of TFRU on overall freeway incident delays.

Pal and Sinha [11] construct a Mixed Integer Programming (MIP) model to determine optimal locations for response vehicles that minimize the annual response vehicle costs, given the frequencies of incidents at potential sites in the network and subject to a constraint on the maximum number of vehicles. Recognizing the highly stochastic nature of traffic and incident management operations, Pal and Sinha [12], introduce a simulation model that can be used for designing a new freeway service patrol as well as improving the operations of existing programs. Opportunity cost-based models proposed by Sherali et al. [13] demonstrate that dispatching the closest available vehicle to the site of the current accident is not always the optimal incident response strategy when considering service to anticipated future demands. However, to make this model polynomial-time solvable, the number of response vehicles required by each incident needs to be same and each depot has to have same number of available vehicles. Ozbay et al. [32] introduce the concept of quality of service and propose mathematical programming models with probabilistic constraints to model this stochastic incident response problem. In their model, multiple potential incidents with various demands for response vehicles are allowed, and the number of available response vehicles at each depot is assumed to be non-deterministic.

Incident Management Programs in the United States

This section gives a brief summary of some of the various incident management programs existing across different states in the United States.

Georgia

Georgia's statewide ITS program, NAVIGATOR, combines video monitoring and detection, data management with telecommunications technologies to verify and quickly respond to highway incidents such as crashes, stalls or debris. This approach, together with the state's Highway Emergency Response Operator (HERO) program, contributed to the average 23-minute reduction in the duration of an incident. The most integrated elements of NAVIGATOR, including the HERO unit, have a benefit-to-cost ratio of 2.3. Equipped to handle anything from a flat tire or stall to a hazardous material spill or serious crash, HEROs assisted more than 33,000 motorists in 1998, with an average response time of less than 10 minutes. The department's Motor Vehicle Emergency Response (MoVER) team is another essential part of the Incident Management program. It is comprised of senior Georgia DOT management officials. Once on scene, they assist other officials in assessing the situation, establishing communications and initiating incident clearance. Providing transportation officials, emergency response agencies, and the traveling public with accurate, reliable real-time information, NAVIGATOR was able to save the state more than $44.6 million in 1997[57]. Based on extremely conservative estimations, these savings are calculated for time alone. The benefits analysis does not consider the benefits or savings in fuel, maintenance or air quality.

Pennsylvania [57]

The Penn-Lincoln Parkway Service Patrol in the Pittsburgh metropolitan area operates during the morning and afternoon peak travel hours. An evaluation of its operation along approximately 32 kilometers (20 miles) compared data from the period of January to April 1997 to incident data collected by the Pennsylvania State Police during the corresponding period in 1996. The data were analyzed to determine the effect of the service patrol on incident response times, incident clearance times, and incident-related congestion factors (i.e., vehicle-hours of delay, fuel consumption, and vehicle emissions). This evaluation yielded the following results: the service patrol reduced incident response times by approximately 8.7 minutes, cleared incidents approximately 8.3 minutes faster than prior to implementation, and reduced hours of delay by approximately 547,000 hours per year. Total monetary savings resulting from implementation of the service patrol are approximately $6.5 million per year [57].

Los Angeles

In the 1970's, the California Highway Patrol (CHP) and the California Department of Transportation (Caltrans) set up an incident management program in Los Angeles. This program began with a surveillance and control system operated by Caltrans, which has evolved from 42 miles in 1971 to currently covering more than 475 miles of freeway in the Los Angeles area. In addition, the system includes ramp meters, detector locations, changeable message signs, and cameras providing a close circuit television system. In July 1991, this program was expanded to include a Freeway Service Patrol (FSP). Under this program, CHP has statutory responsibility for overall management at the site of all freeway incidents, and Caltrans is responsible for system traffic control during major incidents and for maintenance support [(69)]. Clearance of incidents is done by private tow truck operators under the direction of CHP.

At the end of 1992, the FSP was under contract with 88 private tow trucks to patrol the highways, which is being expanded to 140 tow trucks by April 1, 1993. These trucks patrol 250 miles of Los Angeles expressway, and provide as many as 1,000 assists each day. Although consideration was given to establishing a program similar to that in Chicago, it was decided to keep governmental involvement to a minimum, and contract with the private towing industry.
Each agency's primary role was based on that agency's strengths: dispatching and field supervision are managed by the California Highway Patrol while Caltrans' personnel are suited for operations evaluation, fleet management, and evaluation. Currently, 203 miles of freeway are divided into 24 service areas or "beats" that are currently served by 88 tow trucks. These beats range between 5.7 and 13.4 directional miles. The number of trucks per beat is centered around a 15-minute response time. Tow companies are required to provide all equipment and supplies, including gasoline for tow truck operations, gasoline for motorists, and liability insurance. The average cost per hour for these trucks has been established at $45. In addition, a dedicated communication system was provided in these vehicles. Each of the Freeway Service Patrol tow trucks, as

well as the seven supervisory vehicles, are equipped with a dedicated communication system that links them with the Caltrans Operation Center and the CHP Communications Center, including voice radio equipment, mobile digital data systems for two-way non-voice communication, and a teletrack automatic vehicle location system which enables both Caltrans and CHP dispatchers to determine the location of all 88 tow trucks at all times during metro Freeway Service Patrol operations. Since its inception on July 1, 1991, over 60,000 vehicles that had been disabled or involved in minor accidents have been assisted. Motorist surveys show the program has a 98% approval rating. The program has proven to be extremely cost effective due to the competitive bidding process and is believed more cost effective than a state operated program using state employees [(17)].

Michigan

The Michigan Department of Transportation first established television surveillance in the Detroit area in the 1960's, and was the first state in the country to develop a freeway incident management system. Currently, closed circuit television monitors 32 of the 64 freeway miles located within the City of Detroit, in conjunction with 1,350 loops embedded in the pavement in the same area. In 1981, MDOT implemented a project to reduce rush hour traffic congestion, provide instant management, and supply traffic information to motorists [(69)]. This project included surveillance cameras, changeable message signs, motorist aid telephones (which have since been discontinued due to old technology and maintenance expense), and ramp metering. The Department of Transportation currently operates a control center at Sixth and Howard Streets, which continuously maintains surveillance on these 32 miles of roadway. The 1,350 loops imbedded in the pavement are connected to traffic detectors that sense the presence of vehicles, relaying that information to computers that translate the information into traffic volume and speed information. This information is then sent to a computer within the control center that determines the operation of other subsystems, which control ramp metering, and activate changeable message signs to reroute traffic as quickly as possible. In the event that an incident is detected, cameras verify the incident, and this information is relayed to the State Police. This program has been highly successful, with the Michigan Emergency Patrol in the Detroit Metropolitan area reporting that 6,444 incidents were reported on this system through October 1992. Except for the motorist aid telephone systems, a five-year plan to expand this program is in place, and eventually all 250 miles of Detroit metropolitan area expressways will be included.

Chicago

Chicago implemented an Emergency Traffic Patrol (ETP) incident management program in 1960, and currently operates 58 "patrol vehicles" covering 100 miles of expressway 24 hours per day. This program has an annual operating budget of $3.5 million, and is funded from state gasoline taxes [69]. The ETP vehicles are equipped and drivers are trained to handle most traffic incidents, including accidents, disabled vehicles, and small fires. They work closely with law enforcement and fire officials, moving quickly to relocate vehicles that are impeding traffic flow. The primary objective of the ETP is to reduce the exposure of disabled vehicle occupants to high volume/high speed traffic, and to get traffic on the expressway moving smoothly again. Towing is restricted to relocating vehicles only, with a final tow being done by private agencies. The ETP fleet includes 35 emergency patrol vehicles, nine light trucks, three heavy duty recovery trucks, a crash crane, a tractor retriever, a sand spreader, a heavy rescue and emergency lighting truck, and four portable changing message signs, operating twelve patrol assignments on overlapping shifts. In 1991, the fleet logged more than 1.7 million miles. Seven ETP personnel receive special training in all phases of freeway incident management and specific strategies and operational techniques. In addition, they receive training in advanced first aid, CPR, fire fighting, extrication, radio communications, heavy equipment use, emergency recovery procedures, and hazardous materials.

ANALYSIS AND COLLECTION OF INCIDENT DATA

Data Collection

New Jersey Specific Incident Databases

The existing New Jersey incident data set consists of the county incident database, the emergency service patrol database and the emergency incident database. In this section the preliminary analysis results based on the emergency service patrol database and the emergency incident database are presented. County incident database contains the incident information from year 1997 to 2000 for all 21 counties in NJ. In following section, the data modeling and analysis results based on Camden county incident data are presented since the test network used in this study is in Camden County.

Summary of Emergency Service Patrol Data

According to the emergency service patrol database provided by NJDOT, there are nearly four thousand incidents cleared by patrol units during the period ranging from October 2000 to December 2001. In this section the distribution of the incidents are studied; namely, how the incidents are detected, what types vehicles were involved, the number of closed lanes, the locations of incidents, the corrective actions, and types of disablements. The results are illustrated in Table 2 through Table 7

Table 2. Incident Detection Statistics

Detection Type	Number of Incidents
Found by ESP	3169
Dispatched by NJDOT	223
Dispatched by State police	349

Table 2 shows that most incidents are detected by ESP. The rest of the incidents are detected by the DOT or NJ State police. Table 3 shows the type of vehicles involved in the incidents. It can be observed that most vehicles involved are private automobiles. This result is expected due to the high percentage of automobiles in traffic.

Table 3. Type of vehicles involved

Type of Vehicles	Number of Incidents
Other	51
Motor Cycle	1
Combo Truck	135
Single Unit Truck	135
Bus	19
Van	411
Pickup	259
Auto	2623

From the data listed in Table 4, it can be observed that nearly 90% of incidents cleared by EMS are minor incidents in which no lanes are closed.

Table 4. Lane closure statistics

Lane Closed	Number of Incidents
No	3293
Yes	435

When drivers experience minor problems such as flat tire, out of fuel, etc., they usually drive slowly to right shoulder and wait for assistance. Thus, more than 90% of vehicles are at the right shoulder when ESP discovers them. This fact is illustrated in Table 5.

Table 5. Location of involved vehicles

Location of Vehicles	Number of Incidents
Unable to locate	29
On ramp	162
Median	52
Right shoulder	2964
Left shoulder	150
Freeway lanes	320
Other	49

Table 6 shows the corrective actions ESP provides. Accordingly, Table 7 illustrates the distribution of possible disablements the ESP might encounter.

Table 6. Corrective actions

Corrective Action	Number of Incidents
Replace Tire	572
None	141
Added Water	98
Gave Directions	73
Assisted w/ Above Disability	282
Gave Gas	410
Jump Start	90
Self-Aid	450
Towed	458
Tagged	580
Pushed f/ Lanes	63
Various Other	509

Table 7. Type of disablements

Type of Disablement	Number of Incidents
Unknown	498
Other	704
Lock Out	11
Cooling System	189
Fuel System	56
Mechanical	836
Electrical	130
Flat Tire	871
Out of Fuel	434

Summary of Emergency Incident Database

The emergency/incident database contains more than 2400 records between August 1999 and August 2001. The distribution of incident occurrences are studied for the following factors: (1) incident occurrence time, (2) involvement of hazardous material, (3) deployment of VMS/HAR, (4) involvement of NJ State police and (5) the number of closed lanes. The results are presented in Table 8 to Table 11. Table 8 shows that the number of incidents occurred during the peak hours is less than during off-peak hours. However, the frequency of occurrence is much higher due to the fact that the length of the peak period is much shorter than the off-peak period.

Table 8. Number of incidents

Period	Number of Incidents
Peal	885
Off-Peak	1516

Among the emergency incidents, only 2% of these involve hazardous material (Table 9), 16.5% of the incidents require the deployment of VMS or HAR (Table 10), and 25% involve NJ State police (Table 11).

Table 9. Involvement hazardous material

Hazard Material	Number of Incidents
Yes	62
No	2339

Table 10. Deployment of VMS/HAR

VMS/HAR Deployed	Number of Incidents
Yes	428
No	1973

Table 11. Involvement of NJ police

NJ Police Involved	Number of Incidents
Yes	626
No	1775

Table 12 demonstrates that more than half of the incidents can be cleared without any lane closings, while nearly 10% of them are major incidents that result in complete roadway closures.

Table 12. Number of closed lanes

Number of lanes closed	Number of incidents
Ramp	1
None	1558
All	244
3	11
2	98
1	465

From Table 13, it can be observed that highways have relatively higher incident occurrence frequency. This result is mainly based on the fact that traffic volumes on highways are always higher than traffic volumes on local routes.

Table 13. Routes with highest and lowest incident frequency

Route no.	Number of Incidents	Route no.	Number of Incidents
295	441	7	1
73	262	48	1
130	170	83	1
76	136	78	1
42	120	15	1
30	106	109	1
1	105	27	1
35	83	23	1
9	80	278	1
70	78	43	1
38	74	403	1
676	63	4	1
206	59	3	1
322	57	50	1
47	46	80	2
55	45	87	2
40	43	46	2
195	39	22	2
36	38	72	2
37	37	90	2

Figure 4 demonstrates the distribution incident durations. Although most incidents can be cleared in three hours, some extremely serious incidents might take several days to be fully cleared. Nearly 30% of the incidents durations are around one hour.

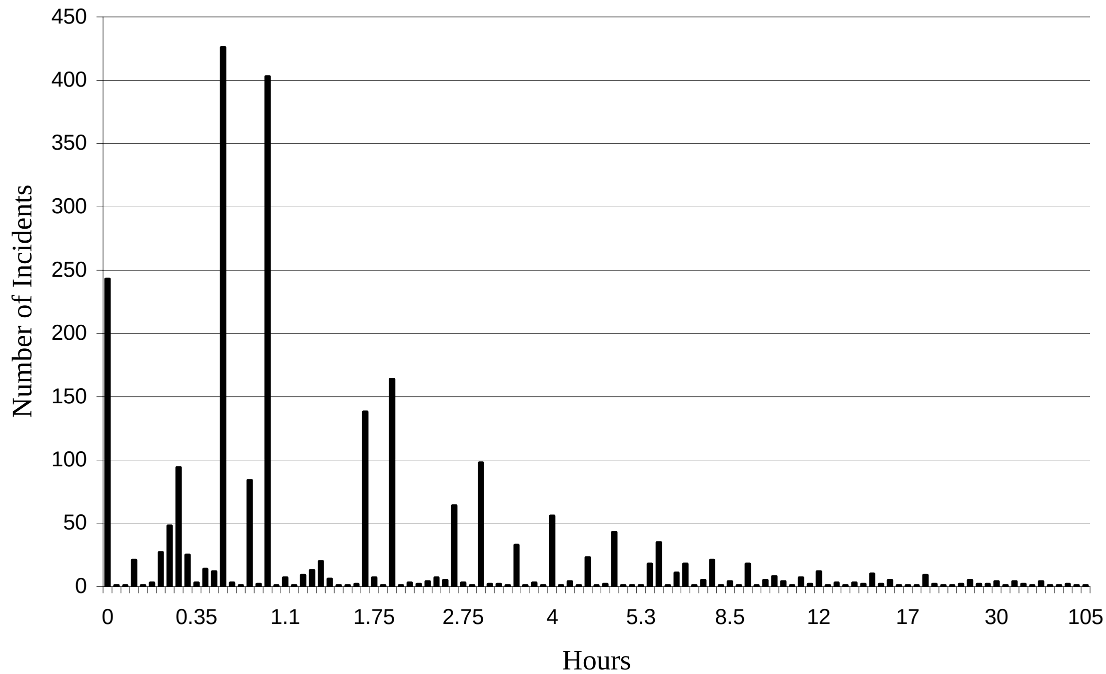

Figure 3. Distribution of incident duration (August 1999 ~ August 2001)

Distribution of Incidents Along Selected Roads

In this section, the distribution of incidents on 5-mile sections along various selected roads are studied to demonstrate the impact of the geometric conditions on incident occurrence. The major highways of South Jersey network are shown in Figure 4. Six of these highways are selected for this study. These are Route 295, Route 73, Route 76, Route 42, Route 30 and Route 1. Attention is also paid to other five routes from other part of New Jersey: Route 80, Route 287, Route 280, Route 440, and Route 24. It should be mentioned that some segments of a route might have much higher incident frequency than other sections of the same route. For instance, the segment of Route 295 between mileposts 25 and 30 seems to be more prone to incidents than other segments.

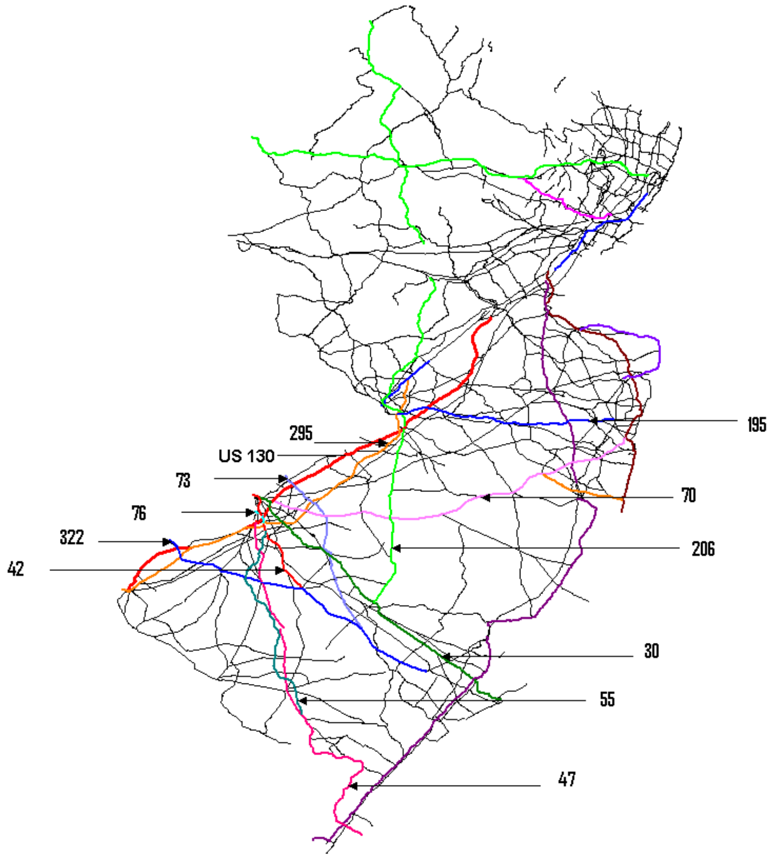

Figure 4. Roadway network of New Jersey and the selected study sites

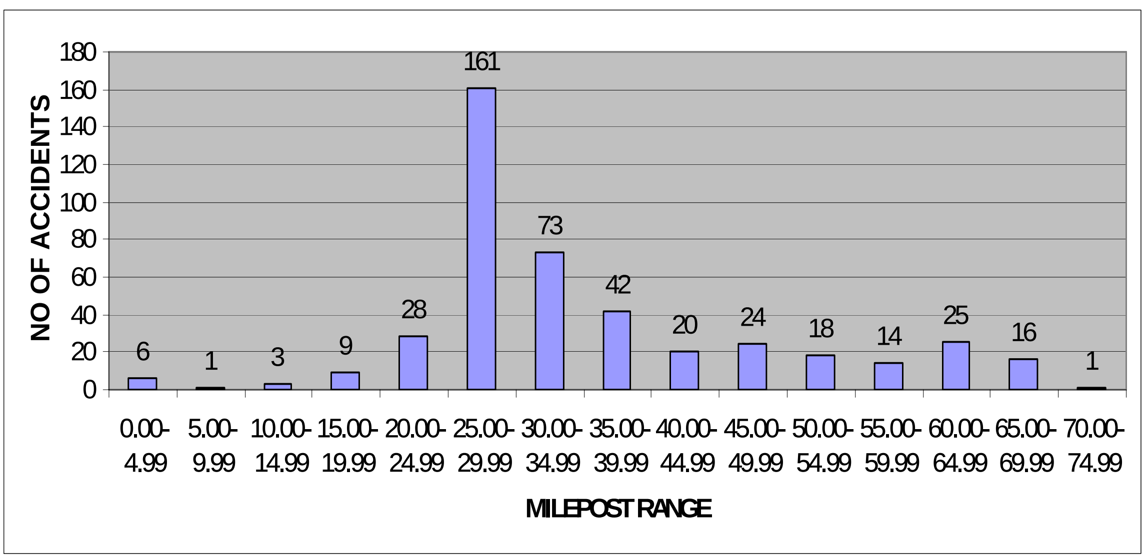

Figure 5. Distribution of incidents along Route 295 (August 1999 ~ August 2001)

Figure 6 is directly taken from NJDOT's 1998 straight-line diagrams. It is safe to say that the sharp curve might be the reason of higher incident frequency in the mile post 25-30 section of route I-295 than other parts, as illustrated in Figure 5.

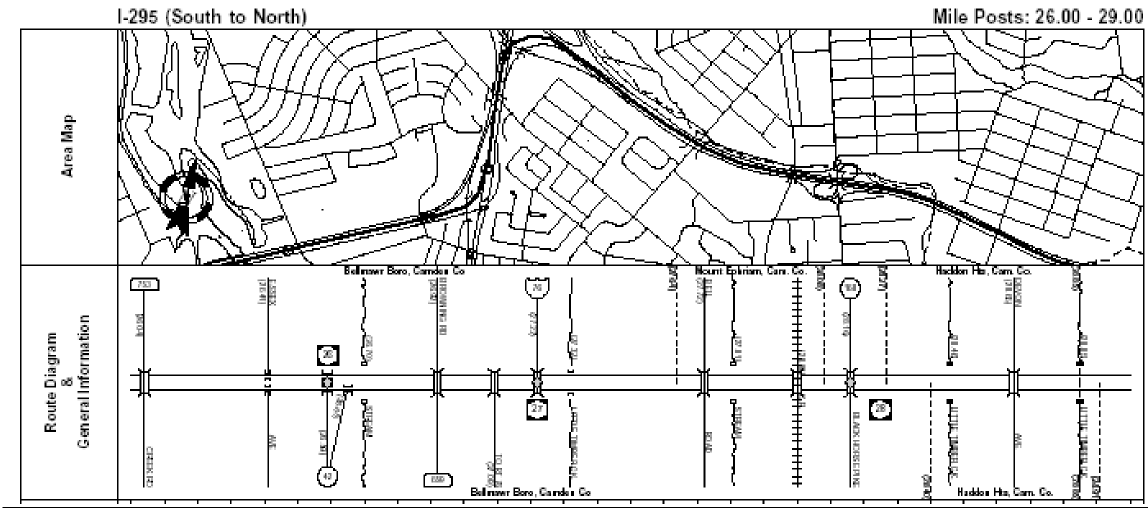

Figure 6. Route I-295 (mile post 26-29)

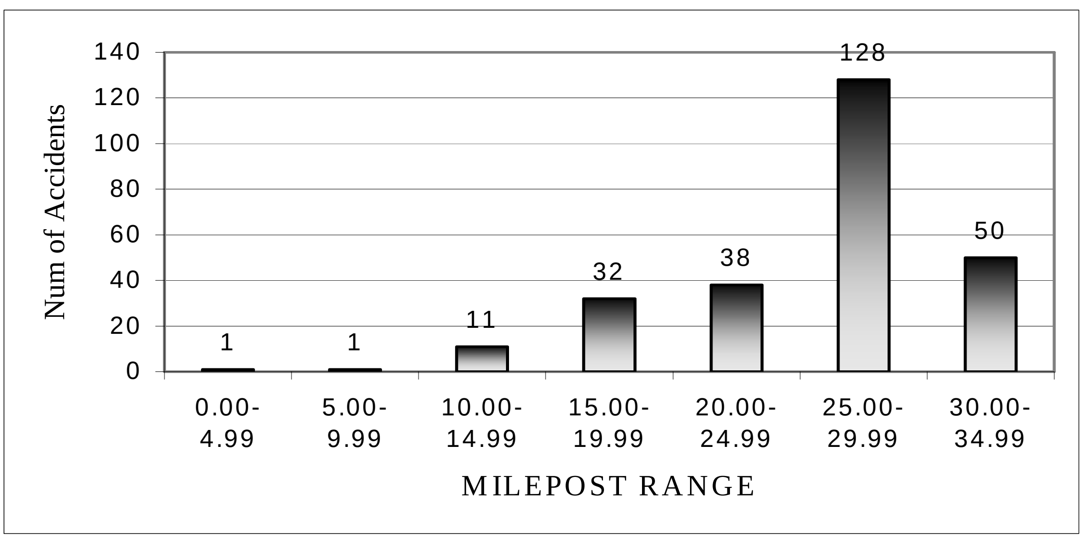

Figure 7. Distribution of incidents along Route 73 (August 1999 ~ August 2001)

If one examines the map of route NJ-73, 5 intersections can be found in the section between mileposts 25 and 30. The high density of the ramps in these segments might lead to the high frequency of incidents, as shown in Figure 7.

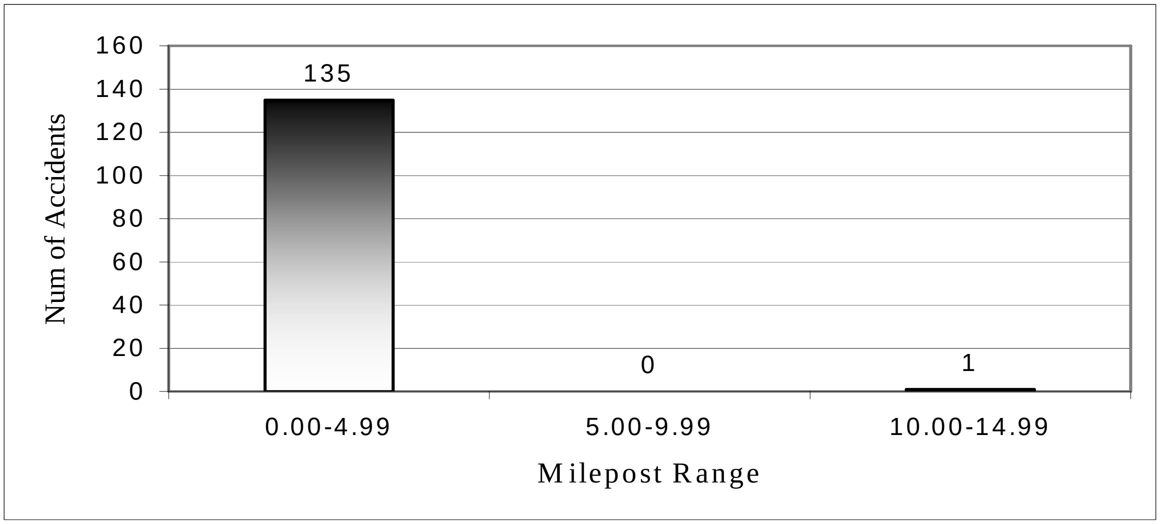

Figure 8. Distribution of incidents along Route 76 (August 1999 ~ August 2001)

The significantly higher incident frequencies observed on the route I-76 section located between the mileposts 0 and 5 (Figure 8), and on the route NJ-42 section between mileposts between 10 and 15 can also be attributed to high density of intersections and sharp curves (Figure 9).

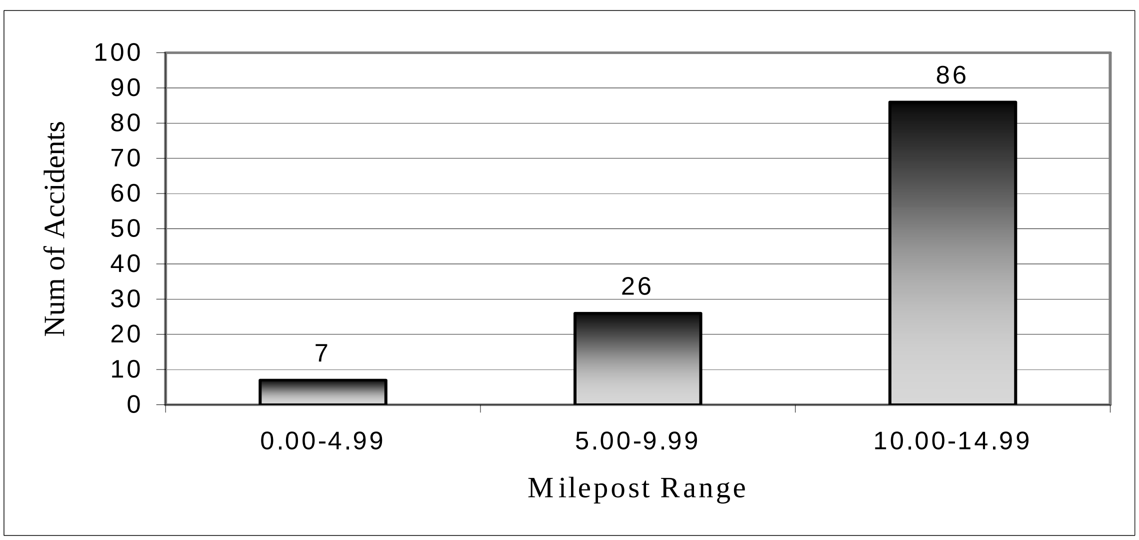

Figure 9. Distribution of incidents along Route 42 (August 1999 ~ August 2001)

Lower number of incidents are observed on US-30 (Figure 10) and US-1 (Figure 11) compared to the other routes mentioned above. It is also observed that the incidents are distributed more evenly on route US-30.

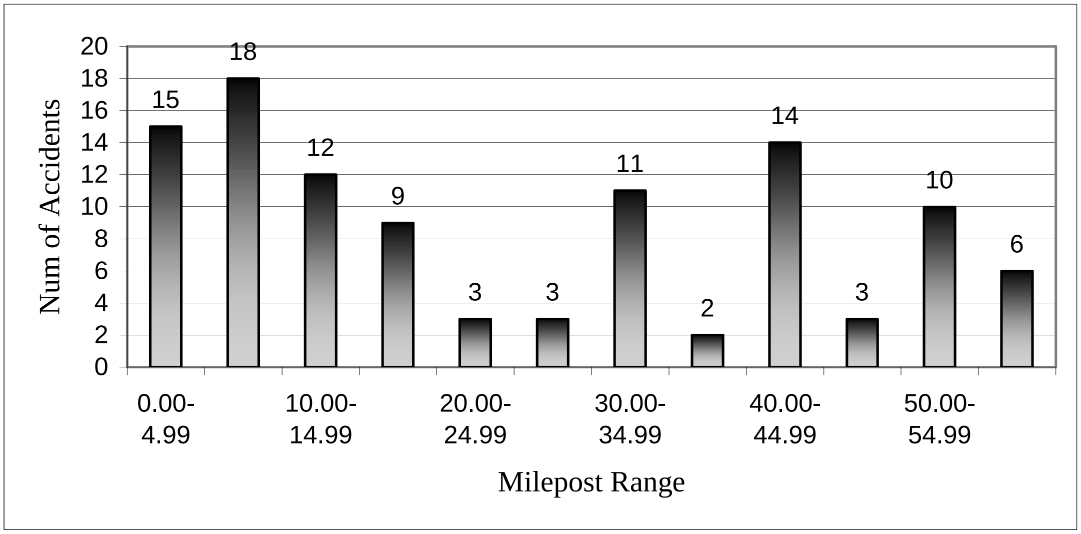

Figure 10. Distribution of incidents along Route 30 (August 1999 ~ August 2001)

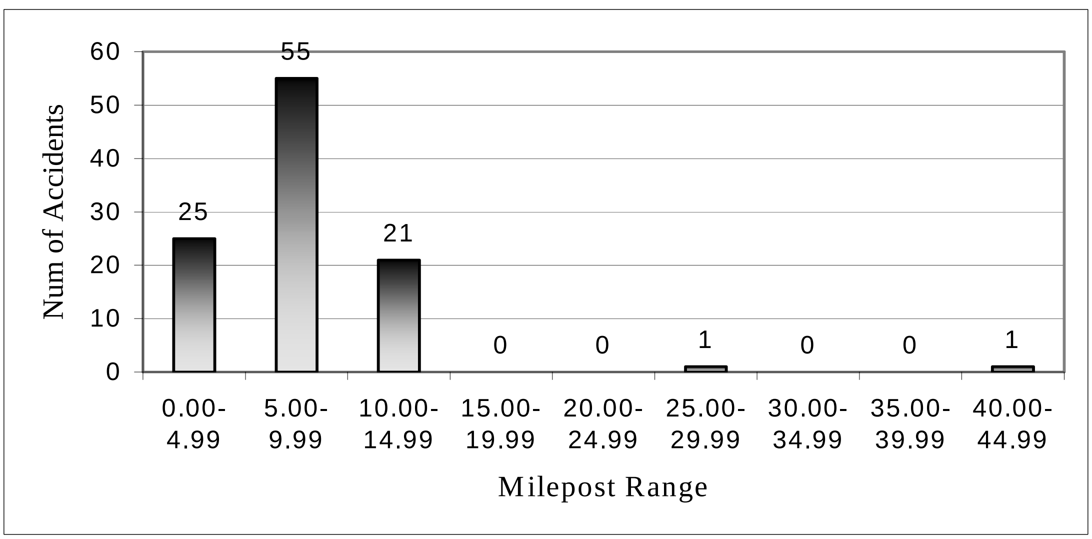

Figure 11. Distribution of incidents along Route 1 (August 1999 ~ August 2001)

Figures 12 - 14 demonstrate the distribution of incident frequencies along I-80, Route 287 and Route 280, respectively. It is observed that the frequency of incidents is proportional to the distribution of traffic volume along thes routes.

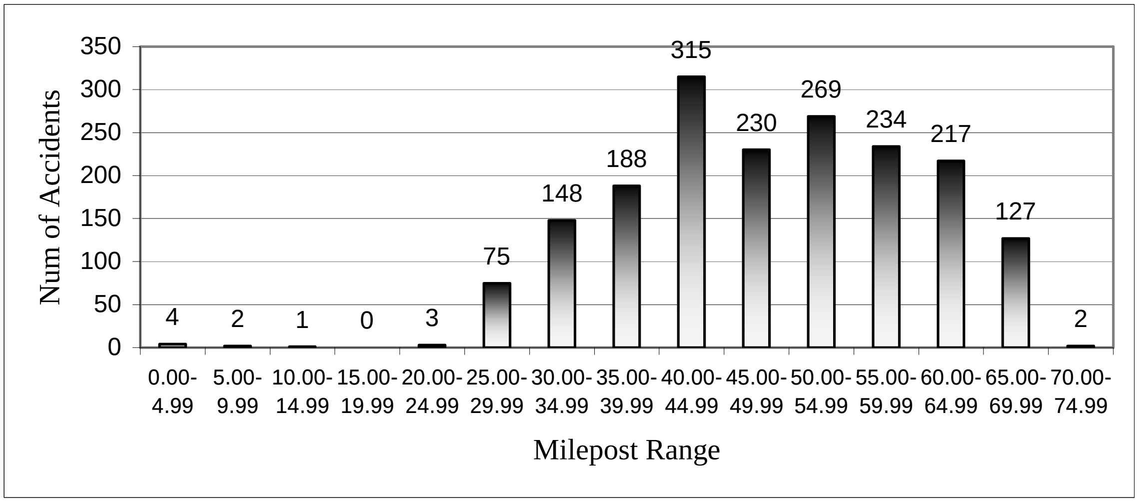

Figure 12. Distribution of incidents along Route 80 (August 1999 ~ August 2001)

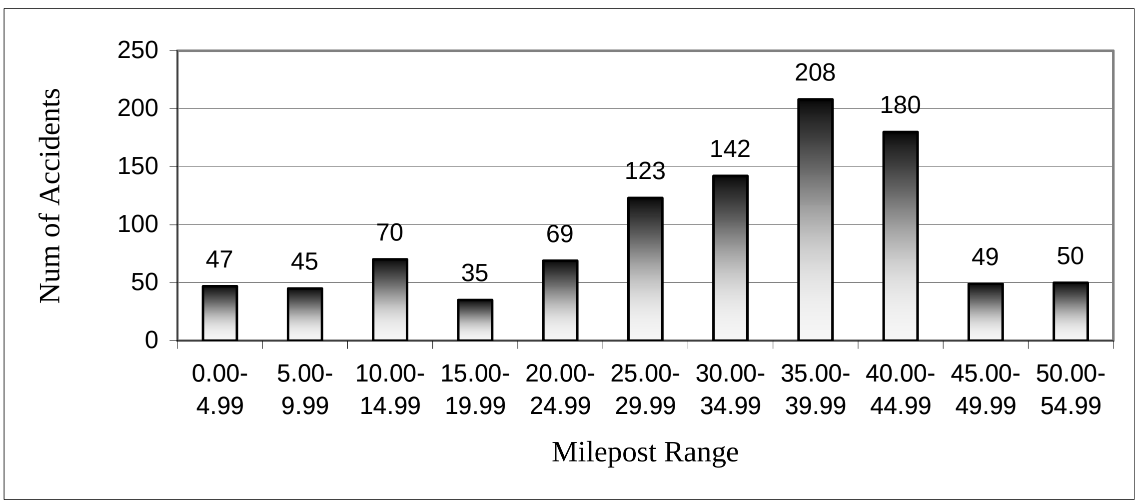

Figure 13. Distribution of incidents along Route 287 (August 1999 ~ August 2001)

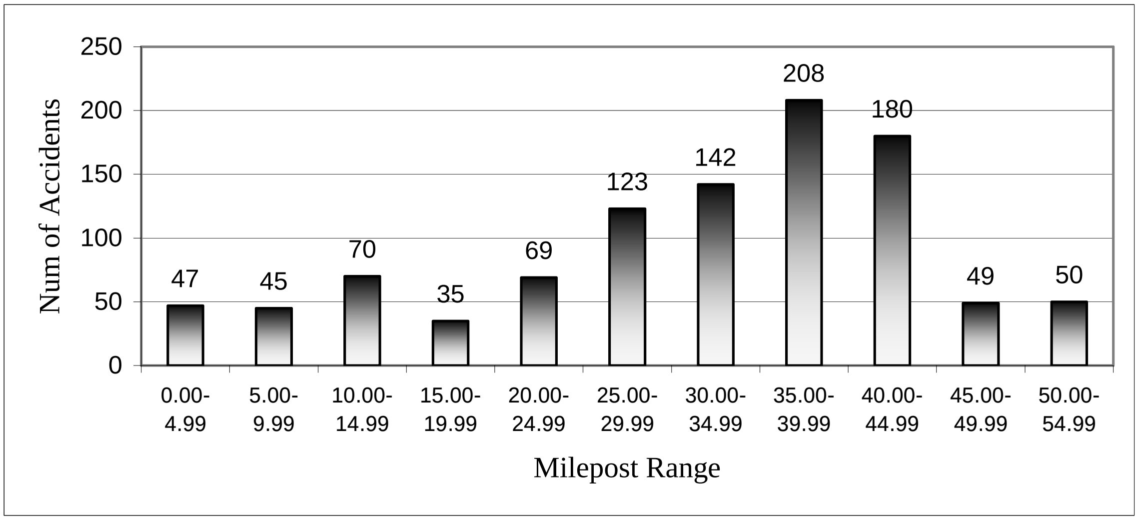

Figure 14. Distribution of incidents along Route 280 (August 1999 ~ August 2001)

Incident Frequency, Duration and Lane Blockage

In this section, the frequency, duration, and the number of lanes blocked during the observed incidents in south Jersey network are studied using on two databases provided by the NJDOT. The county-based database is quite detailed. However, information regarding the duration of the incidents and the number of lanes blocked is not included in this database. Fortunately, these missing data are available in the emergency incident database. The incident frequency analysis is performed based on the county-based database. Alternatively, the modeling of the incident duration and lane blockage is performed using the emergency management database. The geometric characteristics of roads are obtained from NJDOT's 1998 straight-line diagrams.

Incident Frequency Model

This model focuses on 10 major roads in Camden included in the year 2000 incident database. Each road is divided into 1-mile sections, and the number of incidents is considered on a monthly basis. The implicit specification of incident frequency per month as the dependent variable allows the modeling of seasonal variations in traffic volumes, ambient temperature, and other environment data such as daylight duration. Data collected include *incident count*, *the month of* *occurrence*, *highway functional class*, *number of ramps*, *speed limit*, *number of changes of speed limit,* and *number of lanes*. Despite the various shortcomings in quality and incompleteness of the dataset, the data obtained provide a relatively diverse and complete basis for the analysis and modeling.

Poisson regression is often used to analyze count data. It can be used to model the number of occurrences of an event or the rate of occurrence of an event, as a function of some independent variables. In Poisson regression it is assumed that the dependent variable *y*, number of occurrences of an event, has a Poisson distribution given the independent variables $x_1, x_2, ..., x_m$,

$$P(y = k | x_1, x_2, ..., x_m) = e^{-\mu}\mu^k/k! \qquad (1)$$

where *k* is positive integers, and the *log* of the mean μ is assumed to be a linear function of the independent variables. That is,

$$log(\mu) = intercept + b_1x_1 + b_2x_2 + ... + b_mx_m \qquad (2)$$

which implies that μ is the exponential function of independent variables,

$$\mu = exp(intercept + b_1x_1 + b_2x_2 + ... + b_mx_m) \qquad (3)$$

The maximum likelihood method is often used to estimate the parameters of Poisson regression models. In *SAS*, the *GENMOD* procedure can be used to fit Poisson regression models. Table 14 is the output of the parameter estimation analysis.

Table 14. Analysis Of Parameter Estimates

Parameter		Estimate	Standard Error	Wald 95% Confid. Limits		Chi-Square	Pr > ChiSq
Intercept		2.2865	0.0906	2.1090	2.4640	637.31	<.0001
Season							
	Autumn	-0.1579	0.0456	-0.2473	-0.0684	11.97	0.0005
	Spring	-0.0747	0.0446	-0.1621	0.0127	2.81	0.0938
	Summer	0.1531	0.0426	0.0696	0.2366	12.92	0.0003
	Winter	0.0000	0.0000	0.0000	0.0000	.	.
FuncClass							
	Rural Minor Arte	-1.5263	0.7122	-2.9221	-0.1305	4.59	0.0321
	Rural Principal	-1.3858	0.1389	-1.6580	-1.1136	99.58	<.0001
	Urban Freeway	-0.4645	0.1060	-0.6722	-0.2567	19.20	<.0001
	Urban Interstate	0.2205	0.0764	0.0707	0.3703	8.32	0.0039
	Urban Minor Arte	-1.7281	0.3577	-2.4293	-1.0270	23.34	<.0001
	Urban Principal	0.0000	0.0000	0.0000	0.0000	.	.
SpeedLimit							
	25	0.8318	0.4070	0.0341	1.6295	4.18	0.0410
	30	-0.7215	0.1535	-1.0223	-0.4206	22.09	<.0001
	35	0.1774	0.1087	-0.0357	0.3905	2.66	0.1027
	40	0.0535	0.0929	-0.1286	0.2357	0.33	0.5645
	45	0.3621	0.0815	0.2024	0.5217	19.75	<.0001
	50	-0.3643	0.0896	-0.5399	-0.1886	16.52	<.0001
	55	0.0000	0.0000	0.0000	0.0000	.	.
LanesChanges		0.0908	0.0136	0.0642	0.1173	44.80	<.0001
Ramps		0.1597	0.0233	0.1140	0.2055	46.86	<.0001
Scale		1.0000	0.0000	1.0000	1.0000		

From the Wald Statistics test results presented in Table 15, it can be seen that all the factors included in the model are statistically significant (The rejection probabilities as shown in the last column are insignificant).

Table 15. Wald Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
Season	3	52.55	<.0001
FuncClass	5	175.84	<.0001
SpeedChanges	1	14.36	0.0002
LanesChanges	1	15.18	<.0001
Ramps	1	18.10	<.0001

Finally, the incident frequency model is obtained as follows.

$$\mu = \frac{1}{3}\exp[2.2865 - 0.1579(Season:\text{Autumn}) - 0.0747(Season:\text{Spring}) + 0.1531(Season:\text{Summer})$$
$$-1.5263(funclass:\text{RuralMinorArterial}) - 1.3858(funclass:\text{RuralPrincipal})$$
$$-0.4645(funclass:\text{UrbanFreeway}) + 0.2205(funclass:\text{UrbanInterstate})$$
$$-1.7281(funclass:\text{UrbanMinorArterial}) + 0.8318(Speedlimit:25) - 0.7251(Speedlimit:30)$$
$$+0.1774(Speedlimit:35) + 0.0535(Speedlimit:40) + 0.3621(Speedlimit:45)$$
$$-0.3643(Speedlimit:50) + 0.0908 \times LanesChanges + 0.1597 \times Ramps]$$

where, μ is the average number of accidents per month on a 1-mile road segment.

Note that the parameters for those levels that are not listed in the model are zero, e.g. the parameter for "*season*: winter".

Incident Duration Models

Because the incident duration varies dramatically for different types of incidents, the analysis is carried out for each incident type. The categorization and their percentages are listed in Table 16.

Table 16. Incident Categories

Category	Percentage
HAZMAT	4.75
Veh-fire	7.5
Weather	3.98
Disablement-No Blocked Lanes	2.00
Disablement-Blocked Lanes	4.44
MVA-Day Time-No Blocked Lanes	36.45
MVA-Day Time-Blocked Lanes	28.17
MVA-Night Time-No Blocked Lanes	4.9
MVA-Night Time-Blocked Lanes	7.81

The models and their statistical test results for each category are presented in Appendix A.

Modeling of the Number of Blocked Lanes

The number of blocked lanes is a discrete number. The number of blocked lanes is divided by the total number of lanes on that link. The resulting ratio is used to categorize the incidents as shown in Appendix B.

QUANTIFICATION OF COSTS AND BENEFITS OF VARIOUS INCIDENT MANAGEMENT STRATEGIES

The loss due to an incident is sometimes more significant than most would realize, both in terms of the property damage, and time loss of the travelers (i.e. the number of vehicle hours). The steps involved in the incident management process are depicted in Figure 1. This chapter discusses in detail the technologies involved in each step, and the corresponding costs and benefits identified in the literature.

Detection/Verification

Incident detection initiates the incident management process. It occurs when some unusual event is noticed on a roadway. Incident verification is needed when the initial report comes from a sophisticated incident detection algorithm or an untrained commuter who might exaggerate the severity of an incident or confuse the location of the incident along with other details. Sometimes, incidents can be verified by CCTV. More likely, an incident management team or a police officer must be dispatched to the reported scene to assess the situation. It should be noted that actual incidents might require no additional resource other than a single patrol officer, so incident verification and incident response can be a single step in that case.

Many Traffic Management Centers (TMC) also focus on detecting congestion resulting from incidents. They generally determine the congestion on segments of the freeway by comparing traffic parameters such as occupancy, volume, or speed to some set of thresholds. Incident detection is done by comparing the traffic speeds and volumes to dynamically varying thresholds rather than to a single static threshold.

Following is a description of some of the most commonly used technologies for detecting and verifying freeway incidents along with their respective advantages (benefits) and disadvantages (costs).

Video and CCTVs [21]

Close circuit televisions (CCTV) have become increasingly popular for incident detection. They provide visual surveillance of any section of the freeway. They are also sometimes used to verify incident detection algorithms and to determine the severity of an incident, allowing the surveying agency to send the right type of assistance to motorists before response units actually arrive at the scene. CCTV is also particularly useful for traffic flow analysis and for vehicle classification studies.

Example of Current Deployment

San Antonio, Texas - The first phase of the TransGuide system was implemented in San Antonio in 1995 and included 26 miles of downtown freeway. Apart from video surveillance cameras (CCTV), the TransGuide system included dynamic message signs, lane control signs, loop detectors, and a communication network covering the 26 instrumented miles. The system reported a reduction in primary accidents by 35%, secondary accidents by 30%, inclement weather accidents by 40%, and overall accidents by 41%. [22]. Review of video surveillance data collected throughout 1995 indicated an average reduction in response time of 20%. The response times to incidents recorded in the months prior to implementation were compared to those recorded once the TransGuide system became operational. Using the accident frequency for freeways in that area, the results showed an annual savings of $1.65 million. [22]

Benefits/Advantages

- Incidents can be visually verified.
- It allows initial assessment of incident severity.
- It provides a visual record of freeway operations that may be carefully examined at a later stage.
- Volume, speed and vehicle classification data can be gathered simultaneously.

Costs/Disadvantages

- Cable and equipment are not always reliable.
- It provides opportunity for vandalism.
- It may be obstructed by vertical curves.
- Video monitoring is a tedious task, some incidents may be missed or go unnoticed.

$$Cost = Fn(Unit\ and\ installation\ cost, O\ \&\ M\ cost\ per\ unit)$$
$$Benefit = Fn(Delay\ savings\ in\ veh\text{-}hrs, decrease\ in\ fuel\ consumption)$$

Call Boxes and Motorist Assistance Phones [3]

A call box is a box with a switch or toggle that signals the operating agency (via phone line) that an incident has occurred. A motorist only needs to flip the toggle to call for help. Motorist Aid Phones (MAP) include a handset much like a home phone. They are connected directly to the operating agency's dispatch office and no dialing is required. Due to the high costs associated with it, MAP has typically been located at accident-prone locations or along facilities with narrow or no shoulders. Call boxes are widely used today in almost all the states of America.

Example of Current Deployment [22]

Georgia, Atlanta - Georgia Department of Transportation installed a rural call box system along 39-miles of Interstate I-85. The system included 147 call boxes spaced approximately 1/2 mile apart along both sides of the highway. Calls placed from the boxes used cellular technology to contact the appropriate 911 call center directly. Traffic volumes on the interstate were low, with an average annual daily traffic ranging from 13,000 to 67,400 along various segments. Travelers using the call boxes during the first six months of operation reported 920 incidents. The reported benefit cost ratio was 2.76.

Benefits/Advantages

- They provide a safety function (particularly where there are short sight distances as over a crest vertical curve) by preventing secondary incidents.
- Efficient incident reporting can be done.
- Citizen acceptance rate is high.
- Reports directly to response agency dispatch office.
- Allow motorists to report incidents quickly.

Costs/Disadvantages

- Increases operating costs by accruing monthly telephone usage fees.
- Creates a potential for vandalism.

Cost = Fn(Unit and installation cost, O & M cost per unit for service maintenance contract and annual cellular service fee)

Benefit = Fn(Number of injuries and fatalities eliminated, monetary benefit values of the actual calls received)

Loop detectors [(21)]

Within the past two decades, loop detector technology has become the most widely used sensor in incident detection systems. They are capable of measuring flow and occupancy, and estimating vehicle speed. They can also be used to actuate traffic control devices and detect congestion and incidents. There are a wide variety of loop detectors available today, most of them are non-intrusive roadside (or vertical sensors) that do not require pavement cuts nor the disruption of traffic for installation and are primarily point detectors.

Example of Current Deployment

San Antonio, Texas - The incident management system functions that have been implemented as part of Texas DOT's involvement in the FHWA sponsored Model Deployment Initiative include loop detectors, digital communications network, VMS (Variable Message Signs), lane control signals and CCTV. The benefits of the system have already been documented under the discussion for video and CCTVs.

Benefits/Advantages

- When properly installed and maintained, loop detectors continue to be the best in all weather and all light condition, and can be used as sensors for many applications.
- It is the most consistently accurate detector in terms of vehicle counts.
- It performs well in both high and low volume traffic and in different weather conditions.
- Even with crosstalk problems (at Phoenix freeway site) and a high proportion of lane changes (at the Minnesota signalized intersection site), loop detectors had overcounts of only 0.8 percent and 0.4 percent.
- They meet even the most stringent vehicle flow error specifications required by some ITS application.

Costs/Disadvantages

- The loop detector system, may suffer from poor reliability, primarily from improper connections made in the pull boxes and in the application of sealants over the sawcut. These problems are accentuated when loops are installed in poor pavement or in areas where utilities frequently dig up the roadbed.
- Sources of loop malfunction, such as stuck sensors, can produce erroneous data and may lead to inaccurate detection.
- Another disadvantage of loops is their inability to directly measure speed. If speed is required, then a two-loop speed trap is employed, or an algorithm involving loop length, average vehicle length, time over the

detector, and number of vehicles counted is used with a single loop detector.

$$Cost = Fn(Unit\ cost, O\ \&\ M\ cost\ per\ unit\ for\ controllers\ and\ power)$$
$$Benefit = Fn(Monetary\ benefit\ values\ of\ reduced\ incident\ detection\ times)$$

Cellular Phones

Cellular phones have become a very important source for incident detection. They are widely used and are usually very effective as an alternative to infrastructure-based surveillance systems.

Example of Current Deployment [22]

San Francisco, California – An analysis was conducted in the San Francisco Bay area as part of the I-880 field experiment using the California Highway Patrol's (CHP) Computer Aided Dispatch (CAD) incident database. It was observed that cellular phones have the highest detection rate among the detection sources examined. They detected 38 percent of the freeway incidents (accidents and lane-blocking disablements). The combined cellular phones, freeway service patrol (FSP), and the CHP detected 75 percent of all the incidents. The results from the statistical analysis indicated a significant effect of the incident detection source on the incident duration. Incidents reported by cellular phones showed greater incident durations by an average of 14 minutes than similar incidents reported by the CHP or the FSP. This additional delay was due to the incident verification process.

Benefits/Advantages

- Detection is not limited to freeways or a location covered by a TMC, and does not need a substantial infrastructure investment by public agencies.
- TMC operators can locate the geographic location of callers and, therefore, the location of the incident.

- With the average wireless phone market penetration rates in US cities averaging more than 30% (and still growing) and with increasingly competitive fee structures that have considerably increased people's reliance on and willingness to use mobile phones, analyses suggest that most incidents can be reported *within less than a minute from the time of occurrence.*
- Wireless phone users can also detect and report a wider variety of incidents than conventional techniques

Costs/Disadvantages

- One of the disadvantages of relying on wireless phone callers for incident detection is the likelihood of receiving false alarms.
- Callers may not have correct landmark or milepost information in locating the incident.

$$Cost = Fn(\text{Unit cost, O \& M cost per unit for service maintenance contract and annual cellular service fee})$$

$$Benefit = Fn(\text{Number of injuries and fatalities eliminated, monetary benefit values of the actual calls received})$$

Police Patrols [21]

Police patrols during the peak periods, when incidents are most likely to occur and produce high delays results in a quicker detection of incident. This requires additional patrol cars and officers.

Example of Current Deployment [39, 41]

Bay Area, California - The Bay Area FSP (Freeway Service Patrol) is a joint project of the Metropolitan Transportation Commission Service Authority for Freeways and Expressways (MTC SAFE), the California Highway Patrol (CHP) and the California Department of Transportation (Caltrans). During the hours of operation, the vehicles and drivers are exclusively dedicated to patrolling their freeway beat.

The program is intended to augment the MTC SAFE network of motorist-aid call boxes in the nine Bay Area counties. A fleet of 74 trucks patrols some 450 miles of the Bay Area's freeways. Patrol routes are selected based on several factors, including a high rate of traffic and congestion, frequent accidents or stalls, and lack of shoulder space for disabled vehicles. An estimated benefit cost ratio of 11 was observed with FSP.

Benefits/Advantages

- Increased number of response units that are available to respond to an incident.
- Commuters are more receptive to assistance from police patrols.

Costs/Disadvantages

- The increased frequency of patrol units may require upgrading of the dispatch office and/or additional dispatchers may need to be hired.
- Additional costs will be encountered for police salaries, benefits, new vehicles, maintenance of vehicles, and special equipment for incident management.

$$Cost = Fn(\text{Salaries and benefits for personnels, unit costs for vehicles and incident management equipments})$$

$$Benefit = Fn(\text{Veh.hrs of delay saved, gallons of fuel saved in air - polluting emission})$$

Peak Hour Motorcycle Patrols [21]

Officers can implement various accident site management measures to improve traffic flow and safety, such as setting flares and assisting the incident victims.

Example of Current Deployment [25]

Houston, Texas - The Houston TranStar is responsible for the planning, design, operations, and maintenance of transportation operations and emergency management operations within the Greater Houston Area. The Incident &

Emergency Management component of this program comprises of three units, namely, Emergency Communications Unit, Motorcycle Unit and Motorist Assistance Program. The police motorcycle units are very valuable where a freeway incident has stopped traffic. Motorcycles quickly maneuver around traffic to the incident, as compared to a police car that would be caught in the same traffic. The motorcycle officer's response also results in quick and efficient clearance of the incident. Apart from this, the motorcycle unit also shoulders the responsibility of providing basic police services, dignitary and special event escorts, and traffic control.

Benefits/Advantages

- Increased police mobility during peak hour congestion.
- Response times are faster due to increased mobility.
- Expedites the assessment process of the on-site incident severity and thus reduces the time needed for other emergency agencies to respond.

Costs/Disadvantages

- Cost of training the motorcycle patrol officer.
- Motorcycles are usually not able to move a disabled vehicle from the incident site.
- Motorcycles do not offer the same amount of protection as police vehicles to the officer in the event of secondary accidents.

$$Cost = Fn(\text{ Salaries and benefits for personnels, training costs for patrol officers})$$
$$Benefit = Fn(\text{Reduced detection time, reduced response time by other emerygency agencies})$$

<u>Tow Truck Service Patrol</u>

Tow trucks can be specially equipped for freeway incident management and assigned to patrol a freeway segment or to observe from a stationary vantage point and respond to sighted/reported incidents.

Example of Current Deployment [26]

Washington State – Founded in 1963, WSDOT tow trucks have been clearing blockages on the Mercer Island floating bridge. Then in 1989, IRT (Incident Response Team) was highlighted as a pilot program during the Goodwill Games. IRT staff is a specially trained group of WSDOT (Washington State Department of Transportation) maintenance employees who respond to blocking incidents on the state's freeways and highways. Their main function is to clear roads, to help drivers and to restore the normal flow of traffic as safely and quickly as possible. Today the pilot program coupled with the tow truck on the floating bridges has grown to 44 units roving on 35 highway segments during peak periods.

Benefits/Advantages

- They can respond to and clear nearly all incidents.
- They carry gasoline for cars, barriers, flares, and clean-up equipment for small jobs.

Costs/Disadvantages

- When the operating agency opts to provide tow truck service on its own, start-up costs are high.
- Vehicle maintenance and operation costs require funding.
- If a contract is given to a private firm, the investment may be limited to the hours of patrol operation.
- Salaries provided to the operating personnel add up to make this an expensive option.

$$Cost = Fn(\text{Salaries and benefits of operating personnels}, O\&M \text{ cost of towing vehicles})$$
$$Benefit = Fn(\text{Veh - hrs. delay savings}, \text{Reduction in secondary crashes})$$

Aircraft Patrol

The aircrafts/helicopters used for patrolling the freeway system are generally media sponsored, providing traffic reports for television or radio. This type of patrolling is used in many states like Virginia, California, etc. Some agencies are also known to use MEDVAC helicopters for airborne patrols.

Example of Current Deployment [(3)]

Bay Area, California - The California Highway Patrol (CHP) possesses different types of aircraft (AS-350 B3s, OH-58, Cessna 206 etc.) in its aerial surveillance fleet, deployed in eight stations throughout the state. Their helicopters are equipped with CCTVs, Nightsun, moving maps, and medevac capability. The department's air units, with their 37 helicopter pilots and 24-hour a day operations, keep a close watch on the state highways and detect an incident very quickly.

Benefits/Advantages

- It might prove out to be a cheap surveillance option as only one aircraft can provide effective traffic condition information over a large span of area.
- Based on the efficient and accurate traffic (congestion and incident) information provided by the airborne patrol units, there might be major shifts in route choices by the commuters.
- These aircraft can carry a camera and take pictures of the section of the highway where the accident occurred.
- The aerial patrol can quickly detect secondary incidents and accelerate their efficient removal, which reduces their cumulative effect.
- Personnel are able to observe the scene and make real-time decisions in cooperation with other team members. Team members are also able to request additional, real-time information (including zooming to observe names, numbers, materials, etc.) for continuous updating of decisions.

Costs/Disadvantages

- Use is limited to peak hours because usage of aerial surveillance in off-peak hours might prove to be an infeasible option in terms of the prohibitive cost involved.
- Media operated aircrafts are known to impede incident management efforts by hovering too close to the accident site.
- Affected by severe weather conditions.
- Time of detection is a function of headway of aircraft

$$Cost = Fn(Unit\ cost\ of\ aircrafts\ and\ incident\ management\ equipments\ , O\ \&\ M\ cost\ of\ aircrafts)$$
$$Benefit = Fn(Substantial\ reduction\ in\ detection\ times, Reduction\ in\ fatalities)$$

Volunteer Watch (21)

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

Benefits/Advantages

- It provides the citizens with a specific action for reducing congestion in their community because all the volunteers are provided with a particular task to perform, all aimed at reducing congestion in their respective areas.
- It provides visual verification of incidents where other surveillance systems may not have a good viewpoint.
- It provides initial assessment of the severity of the incident.

Costs/Disadvantages

- Volunteers may not be available.
- Training must be provided for reliable reporting.
- As the volunteers are unlikely to be required to follow a strict work schedule, incident detection performance might be “spotty”.

Apart from the above-discussed technologies, the traffic information exchange/communication centers are also used by means of their computer networks, which are connected to the patrol cars to detect/verify a particular incident.

Comparative Performance of Various Technologies For Incident Detection

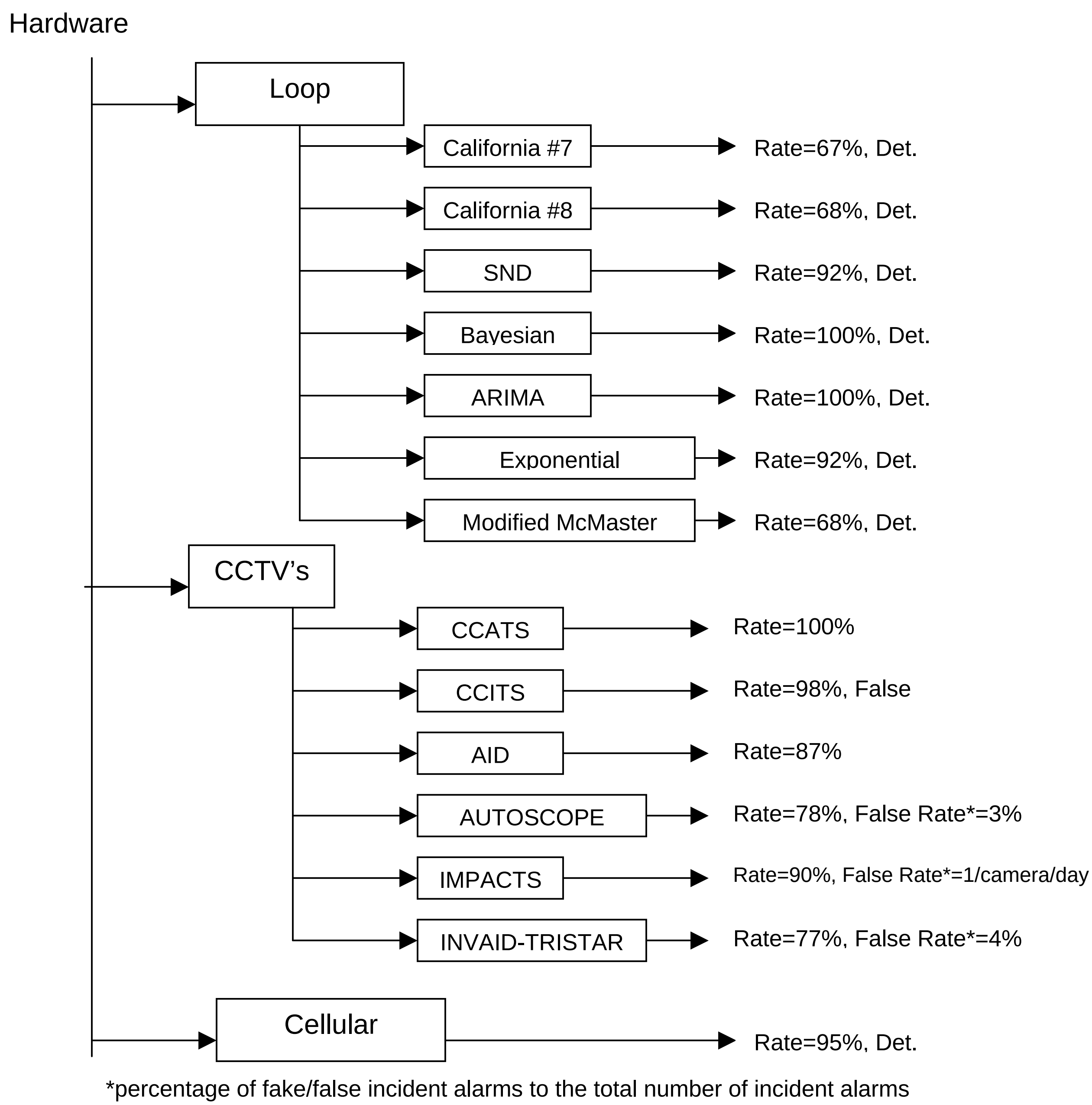

Figure 15. Comparison of various incident detection technologies [4]

Table 17. Comparison of costs of incident detection technologies for freeways [22]

Technology	Unit Capital Cost ($K)		Os & Mt Cost ($K)	
	Low	High	Low	High
Loop Detectors on Corridor (Double set, 4 units)	3	8	0.5	0.8
CCTV Video Camera	7.5	17	1.5	2.4
CCTV Video Camera Tower		12		
Callboxes (each direction per half-mile)		5.9		0.714

Table 18. Comparison of deployment quantities of incident detection equipments for freeways [8]

Technology	Quantity
Loop Detectors per mile per approach lane on Corridor	4
CCTV Video Camera per mile	1
CCTV Video Camera Tower	1

Incident Response

Incident response represents the deployment of resources to the incident. The process includes generating a response plan, dispatching resources, and response by various organizations. The effectiveness of incident response depends on the speed of communication and decision-making, organizational readiness, placement of resources, and travel time to the scene. For major incidents, incident response can occur in stages, where different resources are dispatched for different phases of the clearance process. The data for capital and operations/management costs of the various incident response and clearance technologies is provided wherever available.

Freeway Patrol [21]

This method of deployment is to assign existing police patrol units exclusively to sections of the freeway with high incident rates, except when the police must respond to assist other officers.

Example of Current Deployment [27]

The Hoosier Helper program is a roving freeway service patrol program in Northwest Indiana. The service functions 24 hours a day and 7 days a week. The program maintains a total of six vehicles, with a minimum of two used in the 24-hour service.

Hoosier Helper patrols sixteen miles of the Borman Expressway (I-80/94) near Gary, Indiana. Also, the program patrols an 8-mile section of I-65. The program provides support during incidents, and assists drivers free of charge by changing flat tires, supplying fuel, and calling tow trucks. The estimated total annual benefit of the program for daytime operations was $1.9 million. Total annual cost for these operations was $411 thousand, yielding a benefit to cost ratio of 4.7 for daytime operations (using 1995 monetary values). The estimated total benefit for 24-hour operations for a seven-month study period was $5.5 million. The cost of operations for the same study period were $414 thousand, yielding a benefit to cost ratio of 13.3 for 24 hour operations (using 1996 monetary values).

Benefits/Advantages

- Decreases response time.
- Incident severity can be quickly assessed.
- Minor incidents, such as stalled vehicles, can be rapidly removed

Costs/Disadvantages

- It may conflict with other operating agency budgetary priorities.
- Additional personnel may be required.

$Cost = Fn(\,Salaries\ and\ benefits\ \ of\ \ operating\ \ personnels, O\ \&\ M\ \ cost\ of\ \ service\ vehicles)$
$Benefit = Fn(Non - Recurring\ \ delay\ \ reduction,\ Reduction\ \ in\ secondary\ \ \ crashes,\ Vehicle\ \ operating\ cost\ \ savings)$

Emergency Light Screens

Emergency lights draw attention. To prevent their indiscriminate use, agency guidelines may be established to indicate where necessary reports should be completed off the freeway right-of-way. Portable screens may be used to hide the incident site from other motorists.

Benefits/Advantages

- Decreases the number of secondary accidents by warning motorists of potential hazards.
- Screens increase traffic flow by reducing *gaper's block*.

Costs/Disadvantages

- Passing motorists slow down to look at emergency lights and even screens, resulting in *gaper's block*.
- The screens are flimsy, lightweight, and can be blown away.

Emergency Management Centers

A typical Emergency management center should consist of the following modules:

- **Call tracking** - Identifies and prioritizes calls automatically. A unique number is assigned to every call. Each call automatically receives a priority based on call type. Call priorities can be color coded for easy identification.
- **Dispatching** - Dispatch units based on call requirements. Each unit is precoded by call type. As dispatchers record call information, specific units are recommended for the call. Dispatchers can accept the recommended unit or assign a different unit. Response advisory information is displayed according to the call type.

- **Geographic locating** - Retrieve geographic location automatically based on address information captured from 911. Special conditions for the specified address (such as handicapped person in residence, hazardous materials, etc.) are also provided.
- **Incident recording** - Records name, address and telephone number of the caller. Incident recording can be used independently or in conjunction with dispatching. 911 information can be retrieved automatically.
- **Multi-agency integration** - Dispatch and track police, fire, administrative personnel and units at the same time. Additional agencies are user definable. The dispatcher selects which agencies are active on each incident screen.
- **Records integration** - Transfer completed calls automatically or on demand to the appropriate department including: arrests, incidents, master name, citations, etc.
- **Scheduling** - Emergency management centers should accept unit-staffing information from multiple agencies on a user-defined schedule.
- **Searching** - Retrieve pertinent call, case and/or incident information. Search all records based on any user defined field (for example, search all calls of a certain call type where a specific unit was used during the first shift etc.).
- **Security** - Limit access to information as defined by departmental needs. Data can be protected with view, modify, add, delete and hide permissions down to the field level.
- **Unit tracking** - Track units by user-defined status codes such as in route, arrived on scene, assigned, not available, on duty, traffic stop, suspect stop, available, out of car, etc.

Benefits/Advantages

- It prioritizes the incident calls automatically based on an algorithm, thus saving the time spent in decision process for doing the same.
- It retrieves incident location automatically based on the 911 calls.
- Dispatches and tracks police, fire, administrative personnel, and units at the same time, thus saving a lot of precious time.

Costs/Disadvantage

- The implementation and maintenance costs are high but do not hinder the program's feasibility in high incident prone areas.
- The data security might be prone to illegal hacking.

Table 19. Cost data for a typical Emergency management center [(31)]

Element	Unit Capital Cost ($K)			Os & Mt Cost ($K)[4]			Os & Mt Cost ($K)[5]		
	L[1]	M[2]	S[3]	L[1]	M[2]	S[3]	L[1]	M[2]	S[3]
Computers & Hardware	340 238	272		51 36	41		17 11.9	13.6	
Software	60	60	60				3	3	3
Facilities & Communications	4,000 2,800	3,200		600 420	480		200 140	160	
O & M Personnel							50	50	50

Arterial Signal Control

Arterial signal control systems are used to manage traffic and control the arterial roadways. Included in this, are, arterial traffic management systems that provide surveillance and signal control, and systems that provide travelers with information on arterial street travel conditions through audio or visual displays. Signal control systems are upgraded for a number of reasons, primarily to improve traffic flow and system maintenance. Arterial traffic signal systems provide coordinated control across metropolitan areas. Traffic information may be shared between jurisdictional boundaries and with other metropolitan infrastructure components. Traffic signal control systems include adaptive and

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[1] Large area, Population >= 750,000

[2] Medium area, 250,000 < Population < 750,000

[3] Small area, Population < 250,000

[4] Transcore

[5] Core Infrastructure

transit or emergency priority control. This technology is used in many places, for ex. Michigan, British Columbia (Canada), Toronto (Canada) among others.

The Institute of Transportation Engineers (ITE) estimates that reduction in travel time from traffic signal improvements range from 8% to 25%. Improvements in flow and reducing delays also have a generally positive environmental impact by reducing emissions and fuel consumption.

Benefits/Advantages

- They can reduce the frequency of certain types of accidents, especially right-angle type.
- Helps in reducing travel time considerably.
- Contributes positively towards the environment by reducing the fuel and emission levels.
- Provide travelers with information on arterial street travel conditions through audio or visual displays.

Costs/Disadvantages

- They are very expensive to implement and require a considerable investment.
- There is also a perpetual cost, which is almost never considered – the cost of the electrical power consumed in operating a signalized intersection 24 hours a day, and the associated maintenance costs. These costs can be $1,000 to $2,000 a year.
- Excessive delays may be caused. Even the best-designed and operated signals usually increase delay when compared to unsignalized intersections. However, unnecessary delay is a common feature of an unwarranted or an improperly designed traffic signal. This unnecessary delay results in significant fuel waste and higher motorist costs.
- Delay at unwarranted or poorly designed traffic signals can breed gross disrespect toward signals a well as other traffic control devices.
- Accident frequency can be significantly increased at unwarranted signals or at locations where installation was not based on sound engineering analysis.

Accidents related to signal control usually develop during periods of comparatively low volume and result from rear-end collisions, and drivers either willfully or unintentionally running the red light.

Table 20. Cost data for a typical traffic signal control system (31)

Element	Unit Capital Cost ($K)	Os & Mt Cost ($K)[6]	Os & Mt Cost ($K)[7]
Central Computer System (distributed)	30		
Central Computer System (closed loop)	10		
Coordinated/Adaptive System (Local Controller))	17.5		0.5
Coordinated/Adaptive Master (1 per 20-25 Locals)	10		0.5
Signal Controller Upgrade	5	0.25	
Emergency Vehicle Preemption	2		
Transit Vehicle Preemption	2		
Railroad Preemption	0.5		

Variable Message Signs (21)

Traffic control devices, particularly signs, located along the roadway are the backbone of the traveler information system. The use of changeable message signs (CMS), which display real-time information to motorists, has assisted in efforts to improve roadway operations and safety of existing facilities. These are specially designed, programmed and are strategically located throughout the region. They are used to inform travelers of current unusual traffic or other conditions, such as bad weather. The changeable message sign (CMS) with radar unit has dynamic capabilities, which may be more effective in altering driver behavior. The radar, attached directly to the CMS, determines the actual speed

[6] Core Infrastructure

[7] Seattle Infrastructure

of individual vehicles in the traffic stream. Upon detecting a speed higher than a preset threshold limit, the CMS can display a personalized warning message.

Example of Current Deployment [(29)]

San Antonio, Texas - Nine ITS implementation projects were implemented in the city of San Antonio, Texas, to assist the existing transportation infrastructure in accommodating the growth. A study investigated the combined impact of integrating the VMS with incident management and integrating both the VMS and incident management with traffic signal timing plan alterations along an alternative arterial route.

Results indicate that the most effective stand-alone implementation is incident management, recording improvements in all impact measures assessed. For the particular corridor modeled during this study, optimum implementation of the integrated VMS and incident management resulted in a 5.7% decrease in delay, a 2.8% decrease in crashes, and a 1.2% decrease in fuel consumption annually. It was estimated that an integrated use of incident management, VMS and arterial traffic control would achieve an annual benefit of a 5.9% reduction in delay, a 2.0% decrease in crashes, and a 1.4% decrease in fuel consumption for travelers in the corridor. Focus group studies indicate that customers were satisfied with the VMS system.

Benefits/Advantages

- The same sign can be used for many different messages.
- Drivers can take an alternative route if the sign is placed near an exit.
- Secondary accidents may be reduced with sufficient advance warnings.

Costs/Disadvantages

- Motorists must become accustomed to different messages on the same sign.
- Bulbs and other components need to be regularly serviced.
- There is no set definition of protocols on their operation.
- There are currently no industry standards for CMS.

$$Cost = Fn(Unit\ cost\ based\ on\ type\ of\ VMS, Installation\ cost\ of\ VMS\ tower, O\ \&\ M\ cost\ per\ unit)$$

$$Benefit = Fn(Reduced\ non-recurring\ delay,\ reduced\ number\ of\ secondary\ crashes,\ reduction\ in\ fuel\ consumption)$$

Table 21. Cost data for changeable message signs for freeways (22)

Technology	Unit Capital Cost ($K)		Os & Mt Cost ($K)	
	Low	High	Low	High
VMS	48	120	2.4	6
VMS Tower	25	125		
Portable VMS	21.5	25.5	1.2	2

HAZMAT Response Units [21]

A hazardous material is any substance or combination of substances, which, because of quantity, concentration, physical, chemical, or infectious characteristics may pose substantial immediate or potential hazards to humans or the environment. The working pattern of a HAZMAT unit has the following stages:

1) Sizing up the situation and establishing command.
2) Controlling access to the scene, securing the scene, and isolating the hazard.
3) Identifying the hazard and evaluating the risk.
4) Rescuing and evacuating personnel and victims.
5) Staging the resources - Staging is divided into two levels. Level I involves positioning the standard equipment that occurs as part of any routine response. Equipment and personnel are staged as defined by internal Standard Operating Procedures (SOPs). Level II involves designating an area in a safe location that provides access for the arriving units and for the units that are assigned to work. A Level II area is usually established after the initial size-up is completed. The incident commander ensures that the arriving units are directed into the appropriate staging area.

In HAZMAT incidents, Level II staging is recommended because it keeps uncommitted units in a safe location. The area must be far removed from a HAZMAT scene to prevent the worst foreseeable outcome from affecting operations. The route to the Level II staging should not expose personnel to any danger. When units are expected to be on standby for a long time, the Level II staging may be placed at the nearest base camp. It can also be in another area that is close to the incident and offers the personnel a place to eat, rest, or plan and review their potential role. The incident commander must keep a sufficient level of resources in the staging area to handle any escalation of an incident.

f) Confirming that applicable hazardous-substance-release reporting requirements have been met.
g) Reevaluating the situation.

***Example of Current Deployments* [30]**

Burlington County, New Jersey - In 1988, the Burlington County Office of Emergency Management began developing plans for an organized, effective County - wide response to the increasing possibility of hazardous materials incidents and this led to the formation of Hazardous Materials Mitigation and Emergency Response Unit (HAMMER).

It is available to supplement the efforts of local government fire departments and emergency squads in incidents requiring a higher level of training and more sophisticated equipment, commonly known as technician level capability.

HAMMER provides an effective, professional response to hazardous materials incidents in a safe, expedient and cost effective manner. The team is composed of emergency response personnel certified according to Occupational Safety and Health Administration (OSHA) standards. Team members are qualified to handle a wide range of hazardous materials incidents. The team is strategically located in Burlington County, taking into consideration population centers and transportation corridors, among other things. The HAMMER Unit does not take the place of local emergency response agencies, nor are they responsible for cleaning up hazardous material spills. Clean up of spilled hazardous materials is the responsibility of the person having control over the material. The team's state-of-the-art equipment and supplies are transported in a used box van donated by a local power company, as well as a sixteen-foot trailer for decontamination and spill equipment. While funds for equipping, training and managing the teams are provided by corporate, private, and other volunteer agencies, operating costs are recouped from the parties responsible for incidents to which the teams respond.

Benefits/Advantages

- It takes care of the hazardous materials spilled on the road thus preventing any unforeseen pollution and health hazards.
- It helps in maintaining the current environmental regulations.

Costs/Disadvantages

- It requires extensive inventory of resources like systems, equipment, personnel, and procedures designed to prevent, minimize, or control a hazardous materials release.
- It is very sensitive to the response time for the incidents (or the incident might grow to an unimaginable level).
- It requires frequent training of its team members to keep them updated with the latest technologies in this field and also with the new hazardous materials.

$$Cost = Fn(\text{Salaries and benefits of operating personnels, O \& M cost of service vehicles and incident equipments})$$

$$Benefit = Fn(\text{Delay reduction, Reduction in secondary crashes})$$

Incident Response Teams [31]

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

Example of Current Deployments [32]

Maryland - Initiated in the mid 1980's, Maryland State's Coordinated Highways Action Response Team (CHART) has expanded to a statewide program. CHART is an Incident Response Team managed by the Maryland State Highway Administration. The incident management patrols that are deployed on the CHART network cover 375 miles of freeways and 170 miles of highway arterials. Most of the roadway network covered by the system is located in Baltimore (Baltimore Beltway, I-695), Annapolis, and Fredrick Maryland, and around the Washington D.C. Metro Area.

The system is composed of traffic monitoring, incident response, traveler information, and traffic management components. It was found that the system reduced average incident duration by 57% in 2000 and 55% in 1999. Also it was estimated that the total delay reduction for 1997 due to CHART was approximately 15.6 million vehicle hours and fuel consumption was reduced by about 5.85 million gallons. The reduction in secondary incidents was computed from Maryland State Police accident reports, and was found to be 337 secondary incidents in 1997. A benefit to cost ratio of 7:1 was observed.

Benefits/Advantages

- Teams are prepared to handle unusual incidents.
- Individuals know each other and their roles.
- They reduce the time needed to clear major incident

Costs/Disadvantages

- The co-ordination among the various people can be a problem

$$Cost = Fn(\text{Salaries and benefits of operating personnels}, O \& M \text{ cost of service vehicles and incident equipments})$$

$$Benefit = Fn(\text{Non - Recurring delay reduction, Reduction in secondary crashes, fuel consumption reduction})$$

Media Ties [21]

A good relationship with the media reduces the need for publicly financed information systems, thus deceasing the delay time involved when a highway advisory radio is needed.

Benefits/Advantages

- Frequent traffic reports may allow motorists to delay their departures or use alternative routes, thus easing congestion.
- Good media relations improve the agency's public image.

Costs/Disadvantages

- Personnel must be available for media inquiries.
- Many commercial radio and television stations do not provide traffic information except during the peak hours when it's needed the most.

Highway Advisory Radio (HAR) [21]

HAR is a radio frequency that provides traffic information and potential alternative routes during congested periods. This technology is also quiet widely used in cities like Los Angeles, Atlanta, Houston, Minnesota, Chicago, Seattle, Detroit, Milwaukee etc.

Example of Current Deployment [33]

Detroit, Michigan - A study was conducted using simulation techniques to evaluate the impacts of ITS on the John C. Lodge freeway in Detroit, Michigan. ITS in the corridor consisted of internet-based pre-trip traveler information systems (ATIS), highway advisory radio (HAR), ramp metering, and variable message signs (VMS). The performance of these systems was analyzed through a series of simulations.

The simulation results demonstrated the benefits of existing ITS systems to corridor capacity. The existing ITS technologies in the corridor (ATIS, HAR, ramp metering, and VMS) increased average vehicle speed up to 5.4 miles per hour (mph), decreased average trip time by approximately 4.6 minutes, and reduced commuter delay by as much as 22%. Ramp metering was most effective at reducing congestion during major incidents; however, the study questioned its use in the absence of incidents or during minor incidents.

Benefits/Advantages

- Instant traffic reports are available.
- It helps motorists to decide on alternative routes when they need the information, not when the radio station happens to broadcast it.

Costs/Disadvantages

- Recorded messages become repetitious if not updated frequently.
- Motorists quickly stop using HAR if it doesn't provide timely and accurate information.

$$Cost = Fn(Unit\ cost\ of\ the\ equipment, O\ \&\ M\ cost\ of\ the\ equipment)$$
$$Benefit = Fn(Reduced\ Non\text{-}Recurring\ delay,\ Reduction\ in\ secondary\ crashes)$$

Table 22. Cost data for a highway advisory radio system [(31)]

Technology	Unit Capital Cost ($K)	Os & Mt Cost ($K)[8]	Os & Mt Cost ($K)[9]	Os & Mt Cost ($K)[10]
Portable HAR	50	-	2.5	-

[8] Transcore

[9] Core Infrastructure

[10] Seattle Infrastructure

Other agencies that aid in incident clearance are Law enforcement fleets, fire engines and rescue units/ambulances.

Incident Clearance

Once responding units arrive at the incident scene, they are responsible for any or all of the following:

- Assisting injured parties.
- Controlling hazards and extinguishing fires.
- Clearing vehicles and debris from the scene.
- Controlling traffic and preventing rear end type collisions.
- Disseminating information to motorists.
- Investigating the cause of the incident.
- Reporting their findings.

Some of the most commonly used incident clearance technologies are discussed below.

Towing and Recovery Vehicles [(21)]

The function of the towing and recovery vehicles is to take care of the abandoned vehicle or any vehicle left unattended on a public right of way which poses a hazard to other traffic, or in such a manner that it can be presumed the owner has left the vehicle unattended. Accident recovery work means the towing, removal or movement of a vehicle involved in an accident upon any highway or roadway. Tow means the act by a tow truck of picking up a disabled, abandoned, or impounded vehicle and moving it to a location specified by the owner of said vehicle, or to a location directed by the local police department. A tow truck is a motor vehicle equipped with a boom or booms, winches, slings, tilt beds, wheel lifts, under-reach equipment and/or similar equipment designed for the towing and/or recovery of vehicles and other objects which cannot operate under their own power or for some reason must be transported by means of towing.

Example of Current Deployments [21]

San Francisco/Oakland, California - The Bay Area Freeway Service Patrol (FSP) program has been in operation in the Oakland/San Francisco area since August 1992. Caltrans, the California Highway Patrol (CHP), and the Metropolitan Transportation Commission Service Authority for Freeways and Expressways (MTC SAFE) jointly manage the FSP program. This program relies on vehicles and operators supplied by local private towing firms. The CHP handles supervision, scheduling, dispatching and driver training. MTC SAFE handles contracting with the private tow companies that provide the drivers and patrol vehicles. The coverage area of FSP includes 20 routes and 218 centerline freeway miles. Normal hours of operation are 6:00 am to 10:00 am and 3:00 pm to 7:00 pm, on weekdays. The program consists of 50 light duty tow trucks, one pickup truck, 135 drivers, and a CHP dispatcher. Three of the tow trucks were also evaluated for their performance using CNG fuel. Vehicles that cannot be repaired within the limit specified are towed to the nearest drop site. Abandoned vehicles are tagged by the FSP and are removed from the freeway within 48 hours. Motorists can notify police of an incident from call boxes located along some of the patrol routes. The CHP receives around 1,800 calls per month from the call box system.

The Bay Area FSP program assisted with 97,230 incidents in 1996. The FSP's annual budget is estimated at $6 million. Approximately 60 percent of program funding comes from state funds, 30 percent from local funds, and 10 percent from federal funds. A 1991 evaluation of the program resulted in a benefit/cost ratio of 3.5. The benefit-cost calculation encompassed savings in time, fuel, and vehicle emissions.

Benefits/Advantages

- Provides efficient clearance of abandoned vehicles

Costs/Disadvantages

- The initial investment costs might be high.

- The equipment may often be idle.
- Requires funds for maintenance.
- Requires training for operators.
- Requires an “on-call” crew 24/7.
-

$$Cost = Fn(Unit\ cost\ of\ the\ towing\ vehicle\ and\ towing\ equipments, Salary\ and\ benefits\ of\ the\ operators, training\ costs\ of\ the\ operators, O\ \&\ M\ cost\ of\ the\ vehicle\ and\ equipment)$$

$$Benefit = Fn(Reduced\ clearance\ time,\ Reduction\ in\ fuel\ consumption\ and\ vehicle\ emissions)$$

Table 23. Cost data for towing and recovery vehicles (31)

Element	Unit Capital Cost ($K)	Os & Mt Cost ($K)[11]	Os & Mt Cost ($K)[12]
Special Pickup Trucks	50	2.5	
In-Vehicle Dynamic Route Guidance per vehicle	4		0.4
O & M Personnel		50	
Cellular radio, Communications /vehicle	0.30	0.02	

Patrol Car Push Bumpers (21)

A push bumper is basically a metal bar, covered with a hard plastic coating to prevent scratching, attached to the car’s frame near the bumper and extending in front of the bumper. It allows patrol cars to move disabled vehicles off the traveled way without the need for a tow truck.

Example of Current Deployment (34)

Metro area, Minnesota - The Minnesota Department of Transportation initiated an incident response program known as Highway Helper in December 1987 with three routes covering 40 miles. The program is now called FIRST - Freeway

[11] Core Infrastructure

[12] Seattle Infrastructure

Incident Response Safety Team, and covers 8 routes encompassing 160 miles of metro area freeways. The FIRST provides quick response and removal of congestion causing stalled vehicles, crashes and debris. Each FIRST truck is equipped with a portable message board to facilitate emergency traffic control at the incident scene and push bumpers to clear traffic lanes quickly. Most FIRST personnel, trained as EMS First Responders also assist State Patrol with first aid at crash scenes. They also provide assistance with emergency vehicle repairs.

FIRST assisted approximately 16,737 incidents in 2002. Of the incidents in 2002 that FIRST responded to, 87 percent were detected while patrolling their routes. There were 1,398 lane blocking stalls recorded by the Traffic Management Center (TMC) in 2002, and of that number, FIRST was responsible for detecting and removing 20% of the blocking stalls. Customers report that 79% of the time FIRST responded in less than 20 minutes. Control room operators recorded an average response time to blocking stalls and crashes of eight minutes.

Benefits/Advantages

- All patrol vehicles are able to clear minor incidents.

Costs/Disadvantages

- Liability relating to vehicle damage.

$$Cost = Fn(\text{Unit cost of the towing vehicle and equipments, Salary and benefits of the operators, O \& M cost of the vehicle and equipment})$$

$$Benefit = Fn(\text{Reduced clearance time, Reduction in fuel consumption and secondary crashes})$$

Normal Flow Restoration

This is the process of bringing the traffic flow back to its normal state after it was disrupted due to an incident. The following technologies might be applied for restoring the normal flow of traffic:

Traffic Management Teams (TMT)

A traffic management team comprises officials from all incident response agencies. It provides a framework for interagency co-operation and advance planning. Members meet once a month and have the authority to command their agencies to particular policies and expenditures.

Unlike an incident response team, the traffic management team's purpose is to provide the necessary resources that will result in effective incident response and mitigation. Examples of TMT products are alternative route maps, funding for tow truck patrol etc.

Benefits/Advantages

- TMT provide a forum for interagency co-operation.
- TMTs can develop personal relations between agency and help in improving their communication.
- Agencies can learn about the specific potential abilities and limitations of the agencies they work with.

Costs/Disadvantages

- TMT quickly becomes ineffective if participants are unable to make commitments for their agency.

Pre-Planning For Incidents

A lot of efforts are on for short listing the measures needed to be a part of a decision support system for effective pre-planning for incident management. Following options have been explored:

Alternative Routes

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

Benefits/Advantages

- Route diversion occurs quickly.
- Alternative route recommendations are made quickly

Costs/Disadvantages

- Requires sizeable investment of staff time.
- Some communities do not wish to have any traffic diversion to their streets, regardless of the circumstances.

Emergency Vehicle Access

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

Benefits/Advantages

- Emergency vehicles can approach the incident from both directions.
- Reduces response time.

Costs/Disadvantages

Unauthorized motorists are tempted to use the U-turns.

DEVELOPMENT OF TRAFFIC AND INCIDENT RESPONSE SIMULATION MODEL

Introduction

A computer model is developed to simulate the various activities involved in incident management operation, including incident generation, incident response procedures such as patrolling service and variable message signs, and incident detection. This model provides users with a powerful tool to assess current settings of an incident management system (IMS) or predict the effects of any changes to existing systems. This simulation software package is implemented in C ++ programming language with user-friendly interface and graphic output. This software package is called Rutgers Incident Management Systems (RIMS) software. RIMS can be logically divided into three sub-modules: (1) traffic simulation, (2) incident generation and (3) incident response simulation. Two options are provided for incident generation: Incident generation in accordance with estimated probability distributions, or the direct use of the historical incident data obtained from the NJDOT incident database. Generating incidents according to a given probability distribution can be used to test many what-if scenarios for different incident situations, and it is more flexible than the second option in terms of flexible simulation period and number of simulation replications. Using the historical incident data might better reflect the real-world conditions, but it takes longer to run a single replication and limits the analytical capability of testing hypothetical what-if scenarios.

Traffic simulation is used to realistically simulate the vehicle movements given the origin destination (OD) demands, from which the impact of the following factors on the traffic flow could be demonstrated: number and duration of incidents and techniques employed to detect and manage these incidents. The traffic simulation model is based on the cell transmission model proposed by Daganzo [35].

The incident response simulation model collects the travel time information from the traffic simulation module and simulates the complete incident response procedure. This module is capable of simulating the incident restoration procedure with various types of response vehicles and multiple depot locations. Average incident duration is used as the main Measure of Effectiveness (*MOE*) to compare various resource allocation strategies, service vehicle dispatching policies, patrolling services, and other incident detection and management techniques, such as, CCTV and loop detectors, variable message signs, etc. Two dispatching polices are implemented in this module: FCFS and NN policies as defined in the previous chapter. It is often the case that NN policy outperforms FCFS policy in terms of reducing the average incident duration. The incident response simulation model can also simulate the response operations of a police station, fire department, tow-truck company and hospital in the response to an incident. Decision-makers can then predict the impact of any changes of the location of depots and the number of service vehicles assigned to each depot. The data flow between incident response simulation and traffic simulation is illustrated in Figure 16.

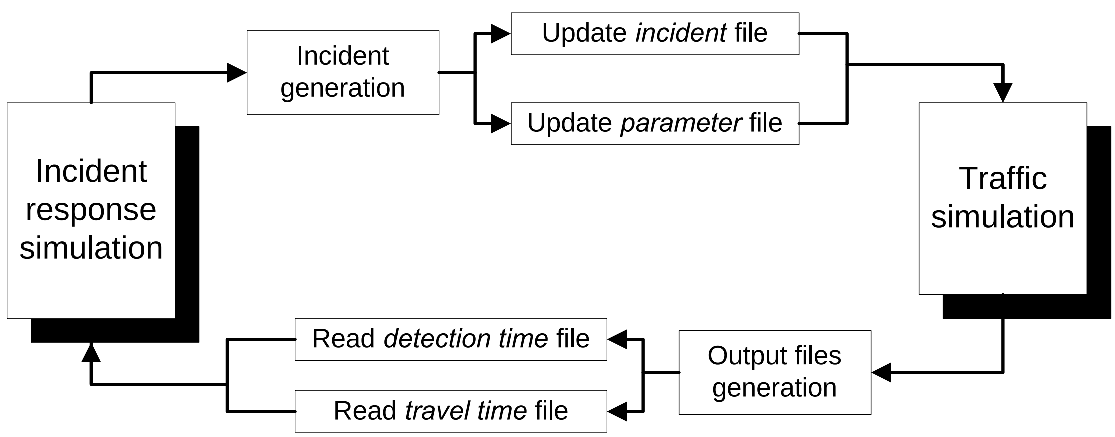


Figure 16. Data flow between traffic simulation and response simulation modules

In the following sections, first the user interface of this simulation program is introduced to provide users with an idea of how the software looks. Then, the implementation of the incident generation, traffic simulation, and incident response modules are explained in detail.

User Interface

This program provides a friendly graphical user interface. Figure 17 is the main window of this simulation program. The middle part of the window shows the simplified representation of the South Jersey transportation network, while the three windows placed on the right-side monitor the simulation process.

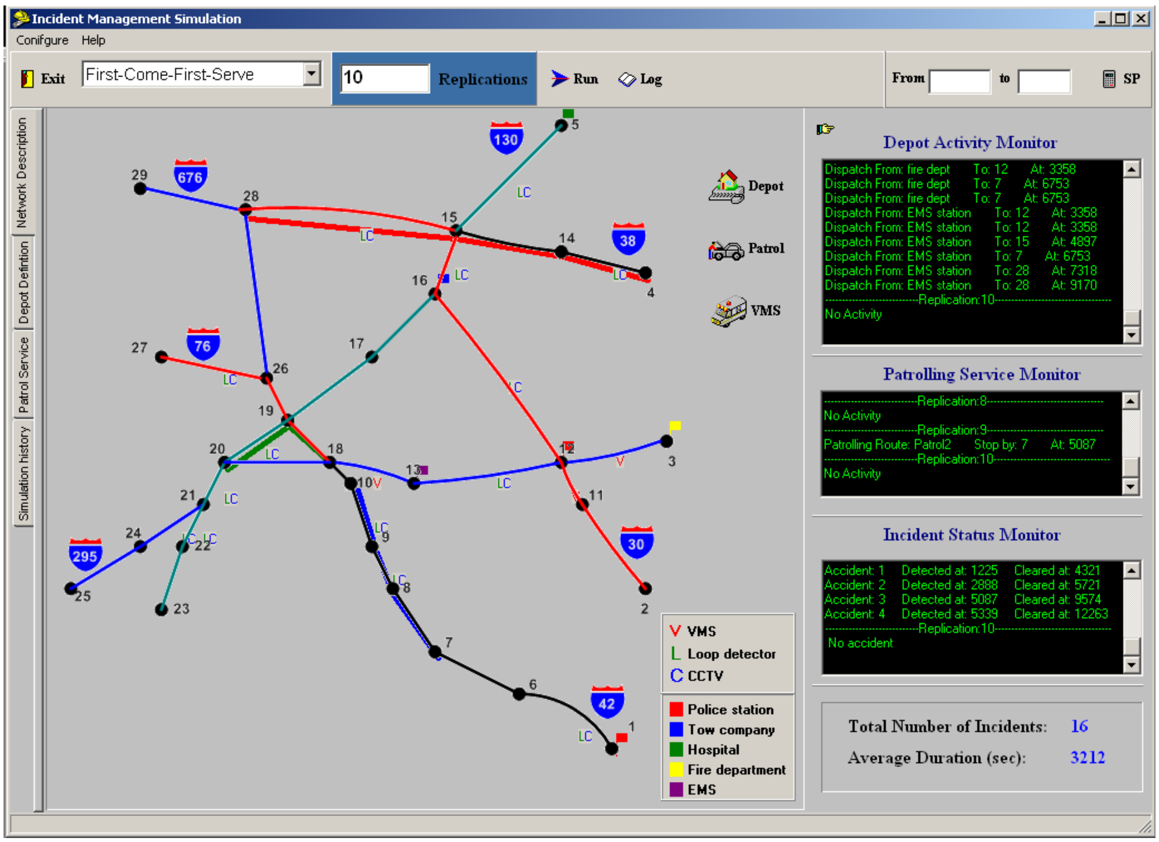


Figure 17. Main window

<u>Input</u>

Before the simulation starts, the following information should be provided: incident generation information, average travel time of each link, depot information (including location, type, number of service vehicles) and patrolling service (including patrolling routes, status, number of service vehicles in each patrolling unit).

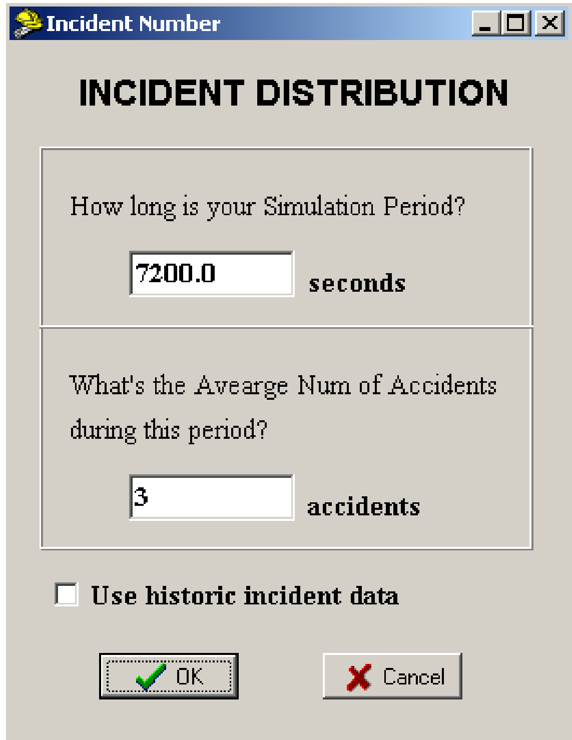


Figure 18. Incident generation

As mentioned above, two methods are used to generate incidents. For example, if the incidents are going to be generated according to a Poisson process, then the simulation period and the arrival rate of the incident should be given through the window shown in Figure 18.

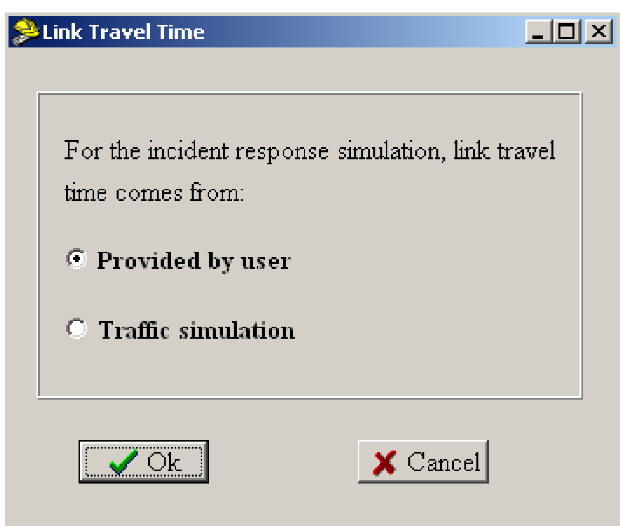
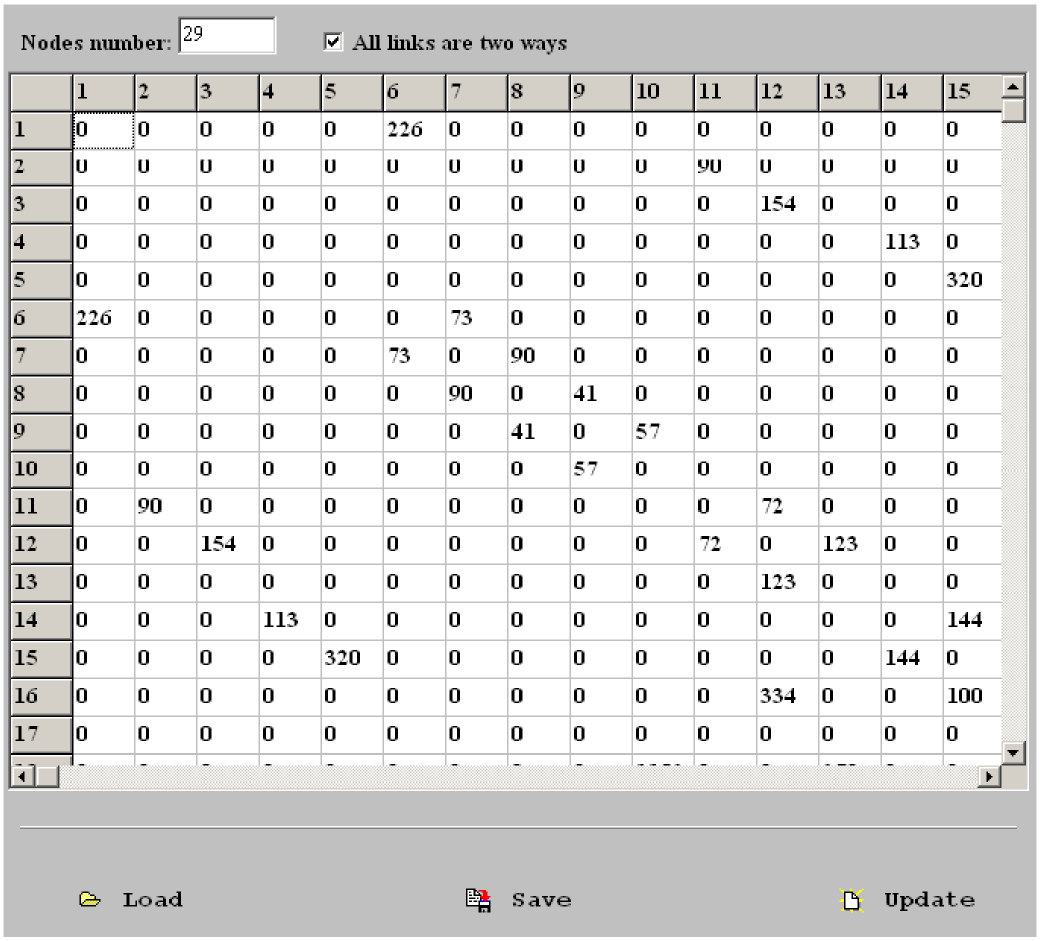


Figure 19. Options for link travel time

As illustrated in Figure 19, two options are provided for the input of the average travel time for each link: collecting the travel time information from the output files of the integrated traffic simulation or reading the existing travel times from the definition data file. The first option assures higher accuracy, but it is very time consuming if traffic simulation is run for every replication. If the travel time does not change significantly over replications, the traffic simulation can be run once. The resulting average time can be recorded as fixed values in the following simulation replications.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	226	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	154	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	113	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	320
6	226	0	0	0	0	0	73	0	0	0	0	0	0	0	0
7	0	0	0	0	0	73	0	90	0	0	0	0	0	0	0
8	0	0	0	0	0	0	90	0	41	0	0	0	0	0	0
9	0	0	0	0	0	0	0	41	0	57	0	0	0	0	0
10	0	0	0	0	0	0	0	0	57	0	0	0	0	0	0
11	0	90	0	0	0	0	0	0	0	0	0	72	0	0	0
12	0	0	154	0	0	0	0	0	0	0	72	0	123	0	0
13	0	0	0	0	0	0	0	0	0	0	0	123	0	0	0
14	0	0	0	113	0	0	0	0	0	0	0	0	0	0	144
15	0	0	0	0	320	0	0	0	0	0	0	0	0	144	0
16	0	0	0	0	0	0	0	0	0	0	0	334	0	0	100
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 20. Input window for travel time matrix

Figure 20 shows the window used to input average travel time for each link. The “node number” text box contains the total number of nodes in this network. The numbers in the first column of the grid box represent the “from” nodes of each link, and the numbers in the first row are the “to” nodes. The zero-value cell indicates that the corresponding link does not exist in the original network. The data input through this window can be saved, uploaded and modified, if necessary.

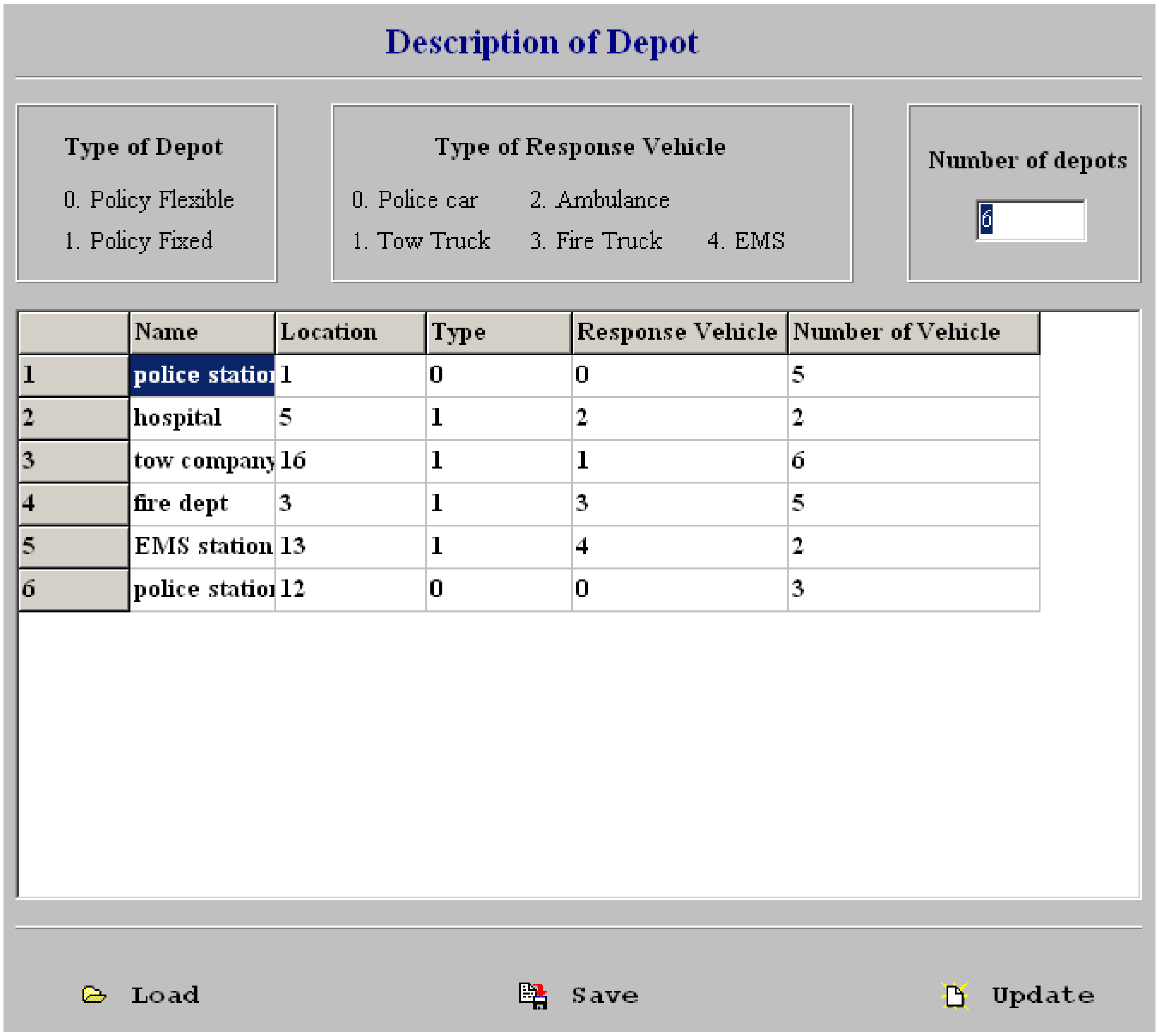


Figure 21. Input window for depots

This simulation model covers nearly every type of service units used in real-world, including police car, ambulance, tow truck, fire truck and EMS. Each service vehicle belongs to a depot and each service vehicle should be dispatched from its depot. The depot properties can be inputted or edited using the window shown in Figure 21. The location of the depot is the identification number of the node where the depot is located. “Response vehicle” specifies the type of the service this depot can provide, and the “number of vehicles” is the total number of service vehicles this depot possesses. Users can change the location of the depot and the number of service vehicles assigned to the depot conveniently and run the simulation to compare the results before and after the change. In other words, different resource allocation strategies can be tested easily through this window.

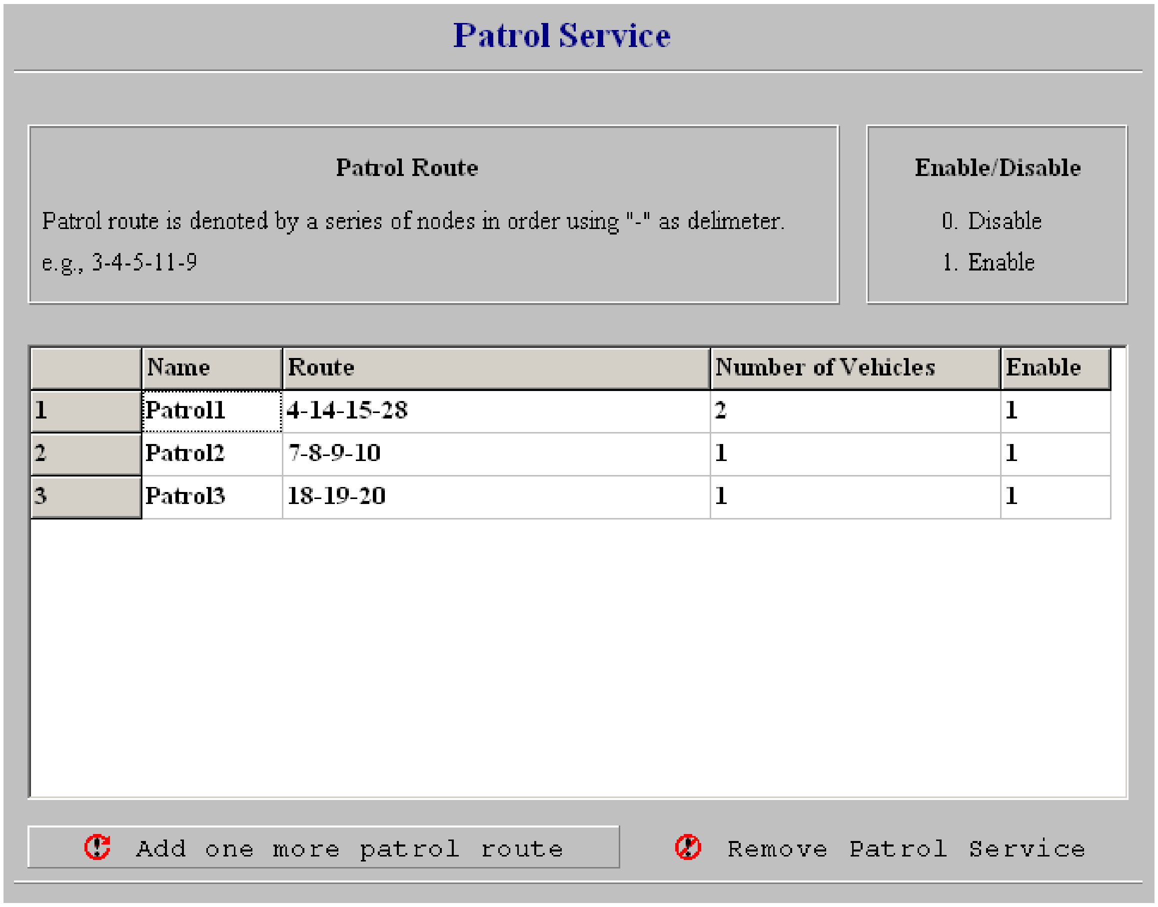


Figure 22. Input and edit patrol information

Patrol service is an important component of the whole incident management system. Patrol service information is input and edited in the window shown in Figure 23. Patrol units run along the route defined by a series of nodes, and turn around when they reach the end of their respective routes.

Users can add, remove, disable and enable a patrolling route conveniently through this interface. The content of each cell is easy to change by double clicking it.

Output

Monitor Windows

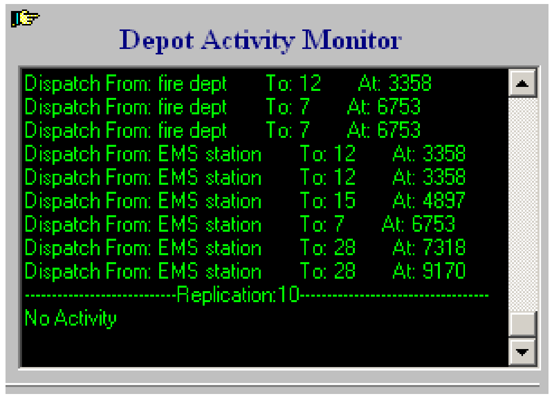


Figure 23. Depot activity monitor window

"Depot activity monitor" window is used to demonstrate the service vehicle dispatching activities in each replication (at what time a service vehicle was dispatched from which depot to service which incident).

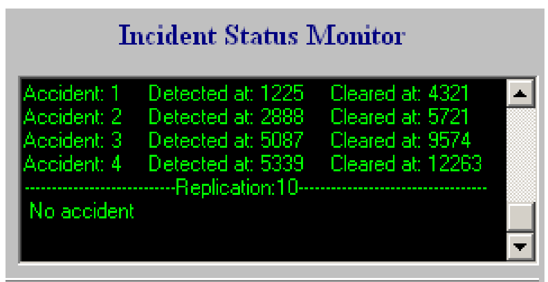


Figure 24. Incident status monitor window

The "incident status monitor" window illustrates the incident response procedure from the incident side. It shows the detection time and clearance time of the incident in each replication.

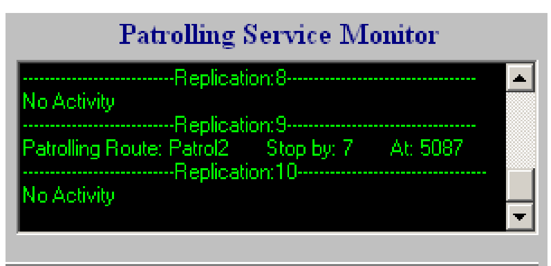


Figure 25. Incident service monitor window

The “Patrolling service monitor” window lists the activities of patrolling service including: where, when, and which patrolling unit clears an incident. It is worth to note that all the text information in above monitors can be copied and pasted to any text editor for analysis purposes.

Simulation History

Simulation results are saved for different scenarios in a tree structure (Figure 26). This makes it convenient to retrieve the previous simulation results or compare the simulation results for different simulation scenarios. By clicking the “+” in the history tree structure, users can determine which changes lead to different simulation results.

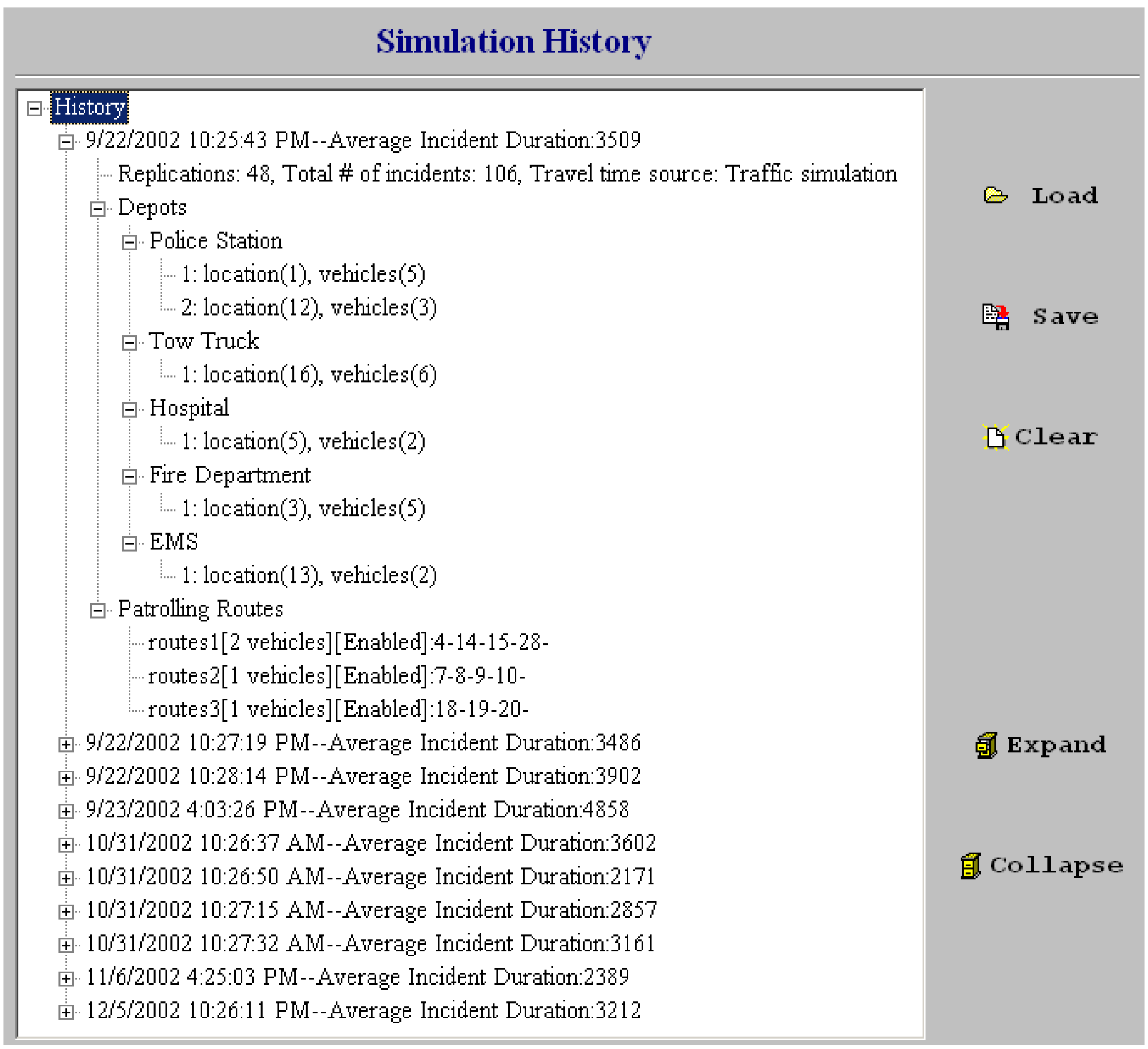


Figure 26. Simulation History

Test Scenario

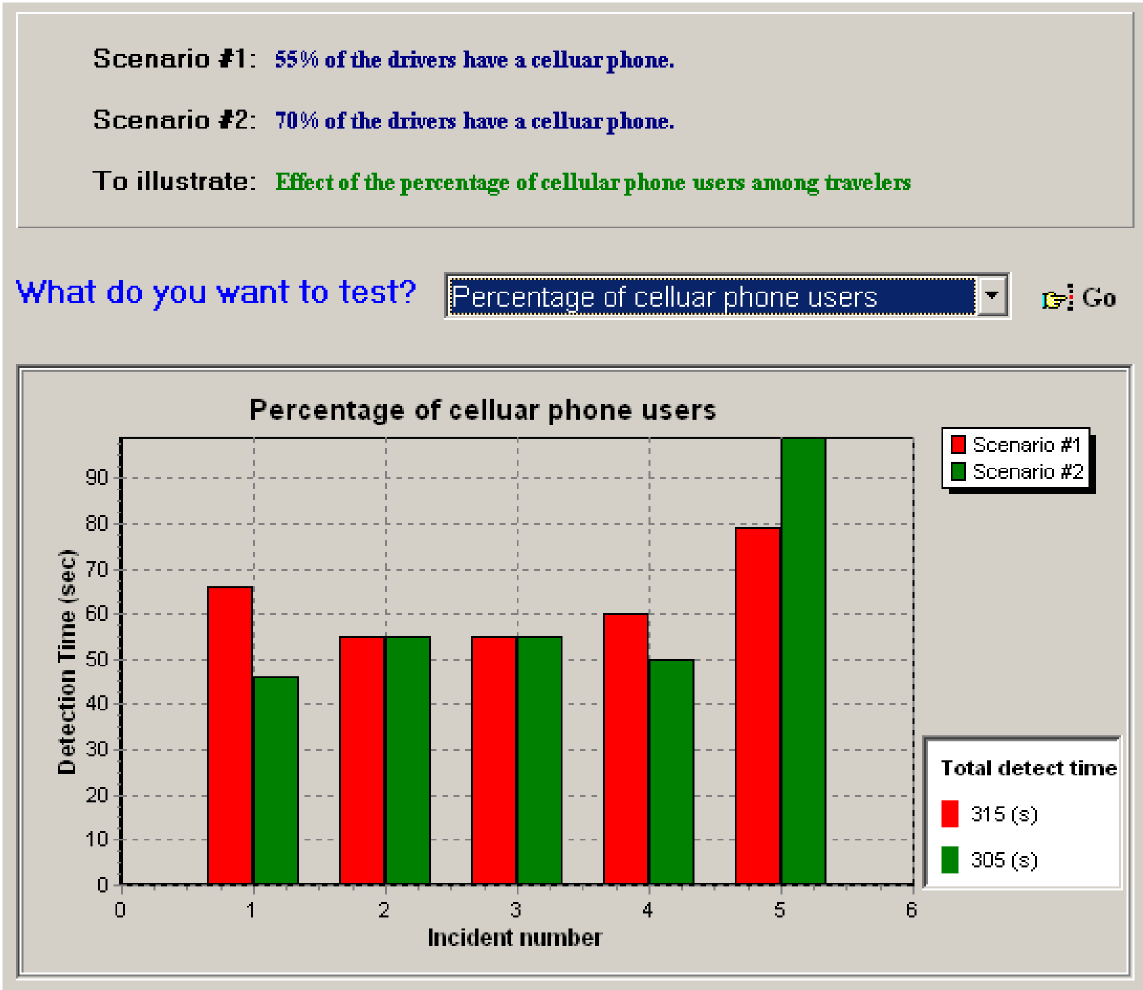


Figure 27. Presentation of test scenarios

Test Scenarios are used to understand the impact of various scenarios on the transportation system using the traffic simulation model for the following five aspects:

(a) Incident with diversion vs. without diversion (route choice available and VMS present in upstream link). The results can be compared and the effect of VMS can be observed through this test.

(b) Effect of changing the split ratios at diversion point (user input in the parameter file) on the link travel times.

(c) Effect of changing the percentage of cellular phone users among travelers on the detection time.

(d) Effect of changing the threshold number of cellular phone calls received before the verification of the incident on the detection time.

(e) Effect of loop detectors and CCTV on incident detection time.

In the "what do you want to test?" list box, end-users can select the factor they want to test. The text in the box changes accordingly to explain the purpose of this test. The test results are illustrated using bar charts, which make it easy to compare the results of two different settings. The difference of the results is also numerically presented in the right bottom box.

Incident Generation

Two options are provided for incident generation. The first option is straightforward. By assuming that the occurrence of incidents is in accordance with Poisson process, incidents are generated with independent identically distributed exponential interarrival times. Since it is not always easy to develop an appropriate model to obtain the incident occurrence rate, another method is provided to generate incidents. As mentioned before the incident data are obtained from NJDOT for a portion of South Jersey network for the year 2000. For each simulation run, a random date from the year 2000 is generated and the incidents that occurred on that day are used as the incidents for that simulation run. All the information of the incidents of that day is employed, including the time of occurrence, location, and severity level. The assumption behind this is that the incident patterns do not change significantly over time. Based on the "real" incident scenarios, decision-makers might be interested in testing what would have happened if they employed another response policy or changed the resource allocation strategies. Since each replication needs to simulate the procedure of an entire day, it is time consuming and not as flexible as the first option.

<u>Generating incident occurrences as a Poisson process</u>

Time of Occurrence

By assuming that incidents arrive in accordance with a Poisson process, the interarrival times are independent and identically distributed exponential random variables. A random variable *X* has an exponential distribution whose probability density function is given by

$$f_x(t) = \lambda e^{-\lambda t} \text{ , } t \geq 0 \quad (4)$$

or, equivalently, cumulative distribution function is given by

$$F_X(t) = \int_{-\infty}^{t} f_x(y)dy = 1 - e^{-\lambda t} \qquad \text{for } t \geq 0 \quad (5)$$

where λ is the rate, t is the time. A random number r_1 (uniformly distributed between 0 and 1) is set to $F_X(t)$, then t can be represented by

$$t = \frac{-\ln(1 - r_1)}{\lambda} = \frac{-\ln(r_2)}{\lambda} \quad (6)$$

where, $r_2 = (1- r_1)$. It is also uniformly distributed between 0 and 1.

Given the rate of incident occurrence, λ, the average number of incidents in the period between t_1 and t_2 is $L = \lambda(t_2 - t_1)$. To generate occurrence time of incidents in this period, exponentially distributed time intervals are generated by using (3) until the total length of time represented by the sum of these intervals exceeds $t_2 - t_1$. This procedure is shown below.

1) Let $T_0 = t_1$.

2) Do

Generate r_2;

$T_i = T_{i-1} + (-ln(r_2)/ \lambda)$

While $(T_i <= t_2)$

It is should be noted that the actual number of incidents generated by this process may not be exactly equal to L.

Location

To achieve a certain level of accuracy in representing the location of an incident, a long link is divided into a number of shorter sub-links by creating virtual nodes.

A virtual node links two virtual sub-links. Figure 28 depicts this method. A 1-mile long link is split into ten 0.1-mile sub-links by inserting eight virtual nodes.

For simplification, it is assumed that incidents occur on virtual nodes or real nodes only. This assumption is a good approximation of the reality if the links are short enough. For *N* incidents detected on a network with *M* nodes (including virtual nodes), their locations are generated as follows:

For (i = 1 to N)

Do: Location (i) = Random (1, M)

Random(n, m) is a function used to generate an integer number which is uniformly distributed between *n* and *m*.

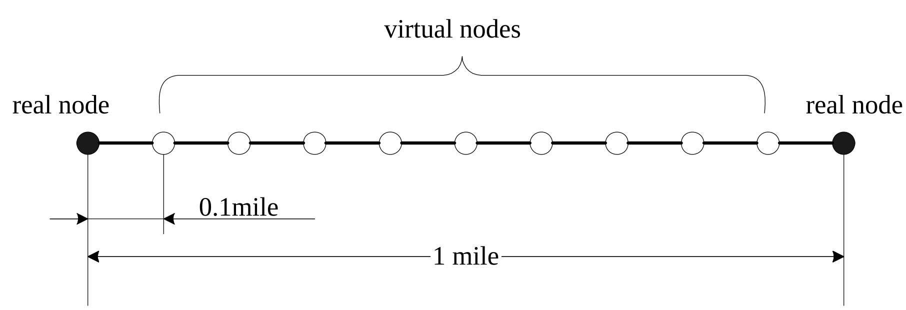


Figure 28. Link Split

Severity Level

The priority (severity) level distribution for a three-lane link is obtained from previous studies by Lindley [36], which is shown in Table 24.

Table 24. Incident Severity Level Distribution [36]

Incident Type	Lanes Affected	Priority Level	Percent of Total Incidents
1	3	7	0.02
2	2	6	0.11
3	2	5	0.72
4	1	4	0.03
5	1	3	3.12
6	Shoulder	2	5.03
7	Shoulder	1	91.97

First, *random(10000)* function is used to generate a random integer number *r* between 0 and 9999 according to a uniform distribution. Then, by checking which interval *r* falls into, the corresponding priority level to this incident is assigned, e.g., the probability of *r is* greater than *13* but less than *86* is

$$P(r > 13, r < 86 | r \sim U(0{,}9999), r\ is\ Integer\ number) = \frac{86-13-1}{10000} \times 100\% = 0.72\%$$

Referring to Table 24 the severity level of this incident is set to 5. The outline of this procedure is shown below.

```
r = random(10000);
if (r < 2)                        then     Severity(i) = 7;
if (r > 1 and r < 13)             then     Severity (i) = 6;
if (r > 13 and  r < 86)           then     Severity (i) = 5;
if (r > 85 and r < 89)            then     Severity (i) = 4;
if (r > 88 and r < 401)           then     Severity (i)= 3;
if (r > 400 and r < 804)          then     Severity (i)= 2;
if (r > 803 and r <= 10000)       then     Severity (i) = 1;
```

Demand For Service Vehicle

This simulation program is capable of simulating the incident response process that requires the involvement of various types of service vehicles, such as police cars, ambulances, fire trucks, tow trucks and EMS. It is assumed that every incident, no matter how serious, must have a police car present at the incident site. The involvement of a specific type of service vehicle and the number of service vehicle requested is determined by the severity of the incident. For instance, an incident that involves injuries or fatalities needs nearly every type of service vehicle mentioned above to be present, and the number of the service vehicles requested should be more than a minor incident.

Service Time

The service time of each type of service vehicle dispatched to the incident is defined as the time between the arrival of a service vehicle and the time that the service vehicle finishes its task. It is found that for a homogeneous subset with enough sample points, the service time generally conforms to normal distribution. Thus, clearance time of *N* incidents can be generated as shown below.

```
For (i = 1 to N)
    Do: SeriveTime (i) = GenNormal (μ, σ)
```

where *GenNormal (μ, σ)* generates a random deviate from a normal distribution with mean μ and standard deviation σ.

Generating incidents based on historical data

For each simulation replication, a date is randomly generated. Then all incidents occurred on that day are picked out as the incidents processed in this replication. The following factors of each incident are collected directly or calculated from the available information as follows.

Time of Occurrence

Time of occurrence is directly collected from the database.

Location

The route number and the milepost where the incident occurred are available in the database. To transform the actual location to the link number used in the simulation program, a *LINKS* table is prepared in the database, whose structure is illustrated in Table 25.

Table 25. The structure of table LINKS

LinkNo	upstream_node	Downstream_node	Length	SRI	Milepost_from	Milepost_to
1	1	6	3.45	00000042	6.18	9.63
2	6	7	1.12	00000042	9.63	10.75
3	7	8	1.37	00000042	10.75	12.12
4	8	9	0.63	00000042	12.12	12.75
5	9	10	0.87	00000042	12.75	13.62

If the SRI of the route and the milepost range of the link are known, it is easy to get the link number via querying Table 25.

Severity Level

The severity levels of incidents are computed based on the number of blocked lanes. If all of the lanes are blocked, the severity level of the incident is set to be 7; if none of the lanes are blocked, the incident is severity level is set to 1. The other severity levels are assigned to the incident depending on the percentage of blocked lanes. The higher the portion of lanes that are blocked, the higher severity level the incident is. Approximately, the severity levels are computed as below.

p = (number of blocked lanes)/(total number of lanes);
if *(p = 1)* **then** *Severity (i) = 7;*
if *(p > 0.8* **and** *p < 1)* **then** *Severity(i) = 6;*
if *(p > 0.6* **and** *p < 0.8)* **then** *Severity (i) = 5;*
if *(p > 0.4* **and** *p < 0.6)* **then** *Severity (i) = 4;*
if *(p > 0.2* **and** *p < 0.4)* **then** *Severity (i)= 3;*
if *(p > 0* **and** *p < 0.2)* **then** *Severity (i)= 2;*
if *(p = 0)* **then** *Severity (i) = 1;*

Demand For Service Vehicles

Since the service vehicle information is not available in the original database received from NJDOT, the number of various service vehicles is generated based on the priority level. Generally, more service vehicles should be assigned to a high priority incident.

Service Time

The police car should be on site during the process of incident clearance until the incident is cleared completely. Thus, the duration of the incident is used as the service time of police cars.

Traffic Simulation Model

The developed traffic simulation model follows the hydrodynamic theory of traffic flow. It assumes that the aggregate behavior of sets of vehicles, easier to observe and validate, depends on the traffic conditions in their environment. The model itself was based on a traffic model called *Cell Transmission Model.*[(35)]

Cell Transmission Model [(35)]

The cell transmission model discretizes the time period of interest (simulation time) into small time intervals. Based on this assumption, every link of the network is divided into small homogeneous segments, called cells, so that the length of each cell is equal to the distance traveled by a free flow moving vehicle during one simulation time interval [(35)].

Based on the above logic, the whole South Jersey network was modeled. The traffic flow data for the network were collected and fed into the model. For the node junctions where there was a route choice available, split ratios for vehicle turns were provided in the input files.

The sample South Jersey network used to test the incident management strategies has five origin nodes and four destination nodes. Boundary conditions were specified by means of input and output buffers. The output buffer, a sink for all existing traffic, was assigned infinite capacity. The input buffer acted as a metering device that released traffic at the desired rate while holding back any flow that was unable to enter the link due to capacity constraints. Following is a description of the evolution of the model, which closely follows the description and notations used in Daganzo [(35)].

The road is assumed to be divided into homogeneous cells, numbered consecutively starting with the upstream end of the road. The length of the cells are set equal to the distances traveled in light traffic by a typical vehicle in one clock tick. To incorporate queuing, two constants were formulated: $N_i(t)$, the maximum number of vehicles that can be present in cell i at time t, and $Q_i(t)$, the maximum number of vehicles that can flow into cell i when the clock advances from t to $t+1$ (time interval t). The first constant is the product of the cell's length and its jam density, and the second one is the minimum of the saturation flow rates of cells $i-1$ and i. Saturation flow rate is essentially the maximum flow rate that can be transferred from $i-1$ to i. The number of vehicles that can flow from cell $i-1$ to cell i when the clock advances from t to $t+1$, $y_i(t)$, is assumed to be the smallest of three quantities:

$x^t_{r,s,i-1}$: The number of vehicles in cell $i-1$ at time t with r as the origin and s as the destination

Q^t_i : The capacity flow into cell i during time interval t

$N^t_i - x^t_{r,s,i}$: The amount of empty space in cell i at time t

The last quantity ensures that the vehicular density on every section of the road remains below jam density.

$y^t_{r,s,ij}$: Flow moving from cell i to cell j from time interval t to $t+1$ with r as the origin and s as the destination

$N^t{}_i$	: Maximum number of vehicles that can be present in cell i at time interval t
P_i	: Set of predecessor cells to cell i
S_i	: Set of successor cells to cell i

Following are the conditions that govern the cell transmission model:

The cell occupancy at time *t* equals its occupancy at time *t - 1*, plus the inflow and minus the outflow; i.e.,

$$x^t{}_{r,s,i} = x^{t-1}{}_{r,s,i} + \sum_{k \in P_i} y^{t-1}{}_{r,s,ki} - \sum_{j \in S_i} y^{t-1}{}_{r,s,ij} \quad . \tag{7}$$

The sum of the vehicle outflow from cell *i* to its successor cells at time *t* cannot exceed the occupancy of cell *i* at time *t*; i.e.,

$$\sum_{j \in S_i} y^t{}_{r,s,ij} - x^t{}_{r,s,i} \le 0 \, . \tag{8}$$

The sum of the vehicle inflow in cell *j* from its predecessor cells plus the cell occupancy of cell *j* at time *t* cannot exceed the maximum number of vehicles that can be present in cell *j* at time interval *t*; i.e.,

$$\sum_{i \in P_j} y^t{}_{r,s,ij} + x^t{}_{r,s,j} \le N^t{}_j \, . \tag{9}$$

The sum of the vehicle inflow in cell *j* from its predecessor cells at time *t* should be less than or equal to the maximum number of vehicles that can flow into cell *j* during time interval *t*

$$\sum_{i \in P_j} y^t{}_{r,s,ij} \le Q^t{}_j \, . \tag{10}$$

The sum of the vehicle outflow from cell *i* to its successor cells at time *t* should be less than or equal to the maximum number of vehicles that can flow out of cell *i* during time interval *t*

$$\sum_{j \in S_i} y^t{}_{r,s,ij} \le Q^t{}_i \,. \tag{11}$$

Figure 29 provides a detailed flow chart explaining the logical flow of the program written to implement the cell transmission model.

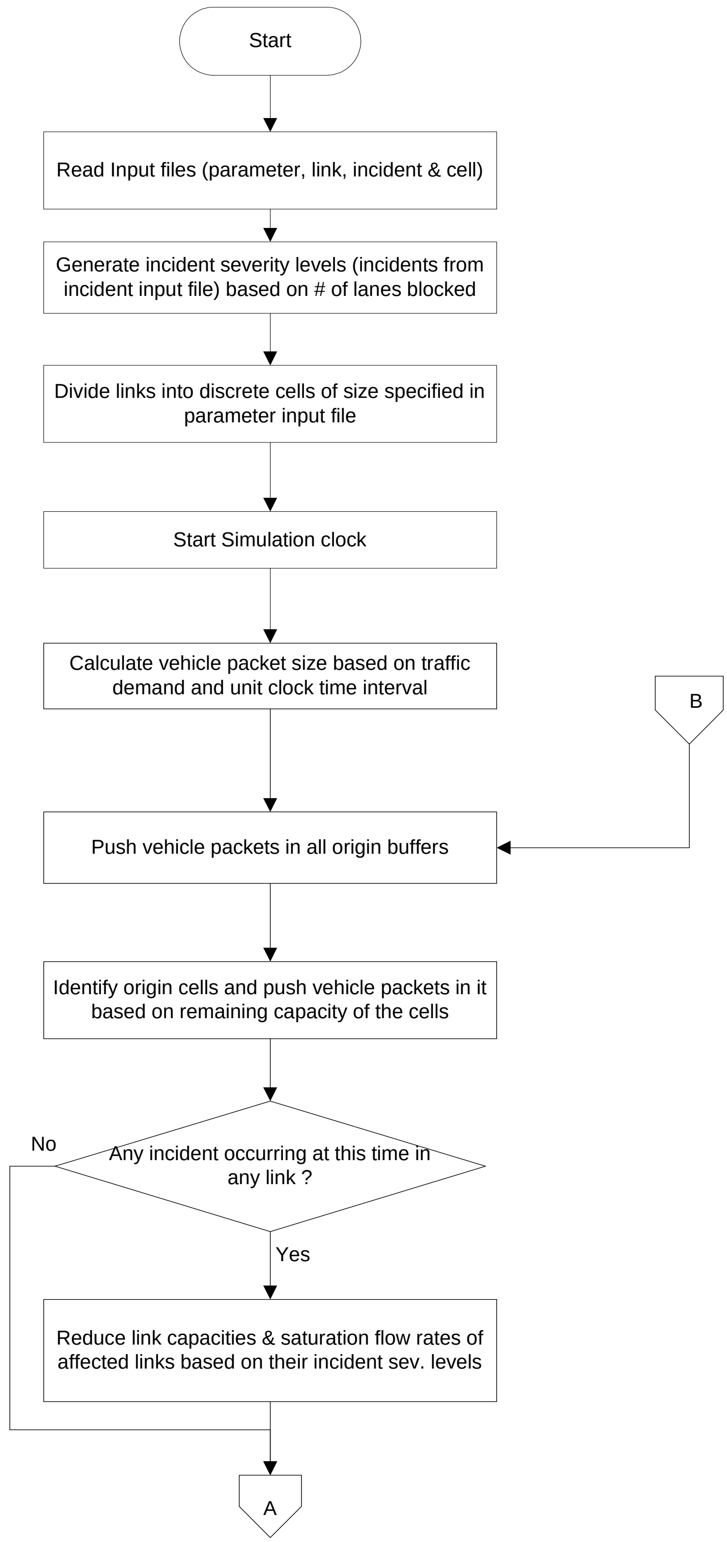


Figure 29. Flow-chart of the program written to implement the CTM

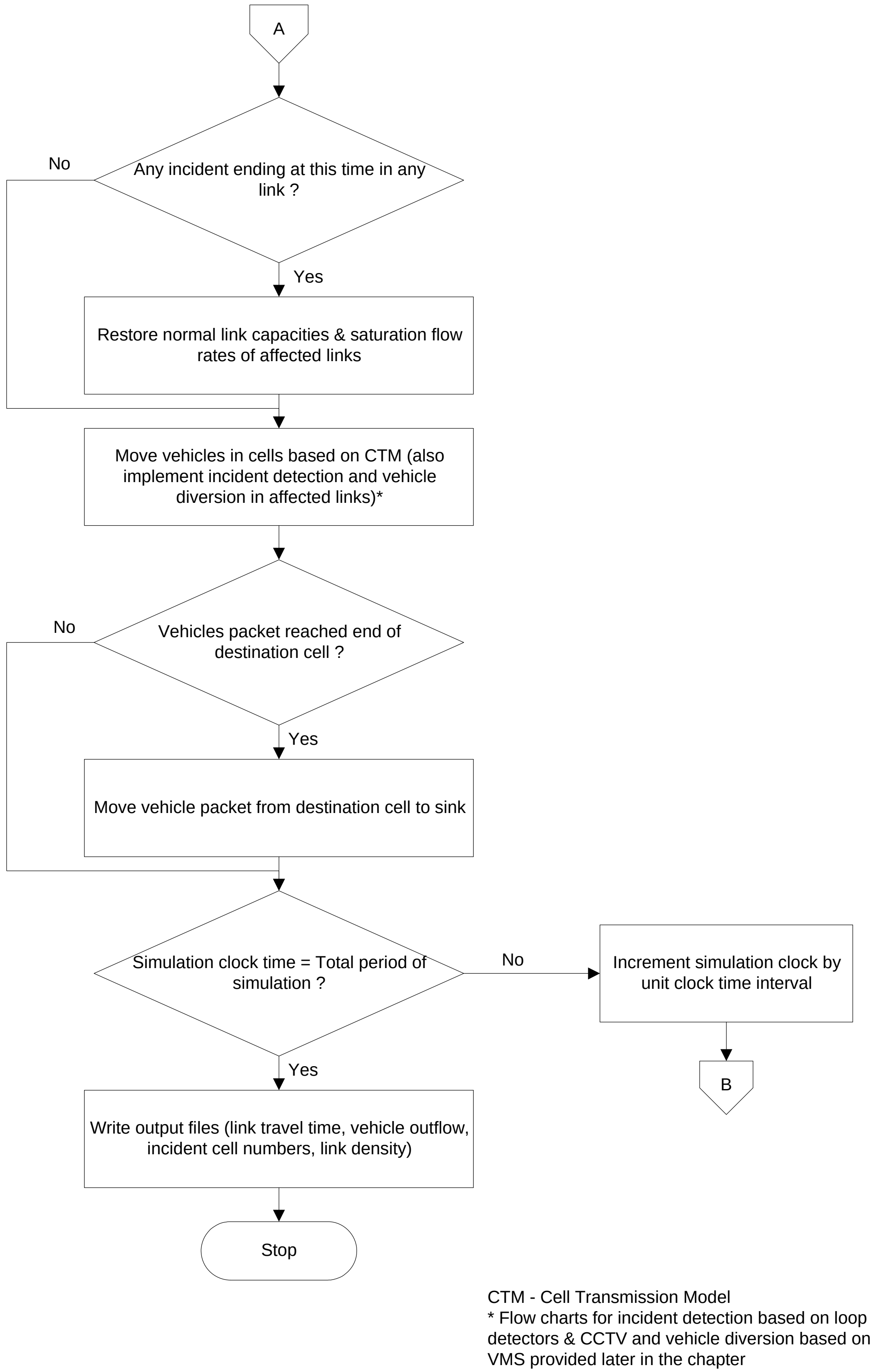


Figure 30. Flow-chart of the program written to implement the CTM (Cont'd)

Incident Scenario Implementation

The simulation model can be used to implement various incident scenarios. These incident scenarios are then used to evaluate the effectiveness of the incident management technologies used in South Jersey test network. The two phases of incident management namely, incident detection and incident response are studied. The technologies for incident detection are, loop detectors, CCTVs and cellular phones, and the technology evaluated for incident response was VMS. Following is the notation used in the flow charts explaining the logic of the modules generating incident detection times based on loop detector, CCTV data and cellular phones and the modules implementing incident response using VMS in the program:

return_det_time: Generates incident detection times in seconds based on loop detector and CCTV data

return_det_time_cellphones **:** Generates incident detection times in seconds based on cellular phone calls made by travelers to report the incident

return_change_in_split_ratio **:** Returns the percentage of the split ratio of all the following links of a diverge link that will remain in case of an incident occurrence in one of the following links

CTM : Cell Transmission Model

i : Incident number

P_i : Percentage of cellular phone users among travelers

N_{TI} **:** Total number of incidents occurring in the network

T_{TS} : Total simulation time (time for which the simulation would run)

T_{cs} : Current simulation time

T_{is} : Incident start time for incident i

T_{ie} : Incident end time for incident i

L_i : Incident link number

L_{iu} **:** Upstream (preceding) link number of incident link for incident i

L_{uj} : Other following links of L_{iu} $j = 1..n$

C_i : Incident cell number

C_{iu} : Upstream (preceding) cell number of incident cell for incident i

T_{sim} : Total time for which the Simulation would run

T_{idc} : Incident detection time based on cellular phone calls made by travelers for incident i

T_{idlc} : Final incident detection time based on loop detector and CCTV data for incident i

M_{idlc} ***:** Mean of final incident detection time (T_{idlc}) based on loop detector and CCTV data (of L_i) for incident i

SD_{idlc} ***:** Standard deviation of final incident detection time (T_{idlc}) based on loop detector and CCTV data (of L_i) for incident i

N_{ic} : Total number of cellular phone calls made by travelers (present in C_i and C_{iu}) to report incident i since the start of i (T_{is}) till now (T_{cs})

N_{TC} : Threshold number of cellular phone calls made by travelers, after which the incident is assumed to be verified

VMS_{Liu} : Variable Message Sign located at the upstream link (L_{iu}) of incident link (L_i) providing information about incident i

R : Random number between -1 and 1generated by the program

$step\_len$: Small time period by which T_{cs} is increased

* If loop detector present and CCTV absent in L_i, $M_{idlc} = M_1$ and $SD_{idlc} = SD_1$

If loop detector absent and CCTV present in L_i, $M_{idlc} = M2$ and $SD_{idlc} = SD_2$

If loop detector absent and CCTV absent in L_i, $M_{idlc} = M_3$ and $SD_{idlc} = SD_3$

If loop detector present and CCTV present in L_i, $M_{idlc} = M_4$ and $SD_{idlc} = SD_4$

The following sections describe the proposed methods to simulate the effects of incident management technologies mentioned in previous chapters.

Effects of Incident Detection Technologies on Traffic Flow

Rapid detection is a critical element in the incident management process. The sooner an incident can be detected, the quicker a response to clear the incident can be initiated. Technologies available for detecting incidents range from low-cost non-automated methods to sophisticated automated surveillance techniques requiring extensive public agency investments. It should be noted that emerging ITS technologies offer promise for dramatically improving detection capabilities and reliability.

The simulation model focuses on the following incident detection technologies:

- Loop detectors
- CCTVs
- Cellular phones

The relevant modules generate incident detection times based on the data available for the above technologies for the South jersey network. The following sections discuss the implementation of these modules in the model.

Incident Detection Using Loop Detectors and CCTVs: Loop detectors supply several pieces of information about prevailing traffic conditions, including vehicle presence, flow, occupancy, and velocity. A good loop detector system is cited as accurate to within five percent. The accuracy and consistency of detector output is a strong function of installation and calibration procedures. Loop detectors are limited by their inability to detect stationary vehicles.

Following is a flow-chart explaining the logic of the module (*return_det_time)* generating incident detection times based on loop detector and CCTV data:

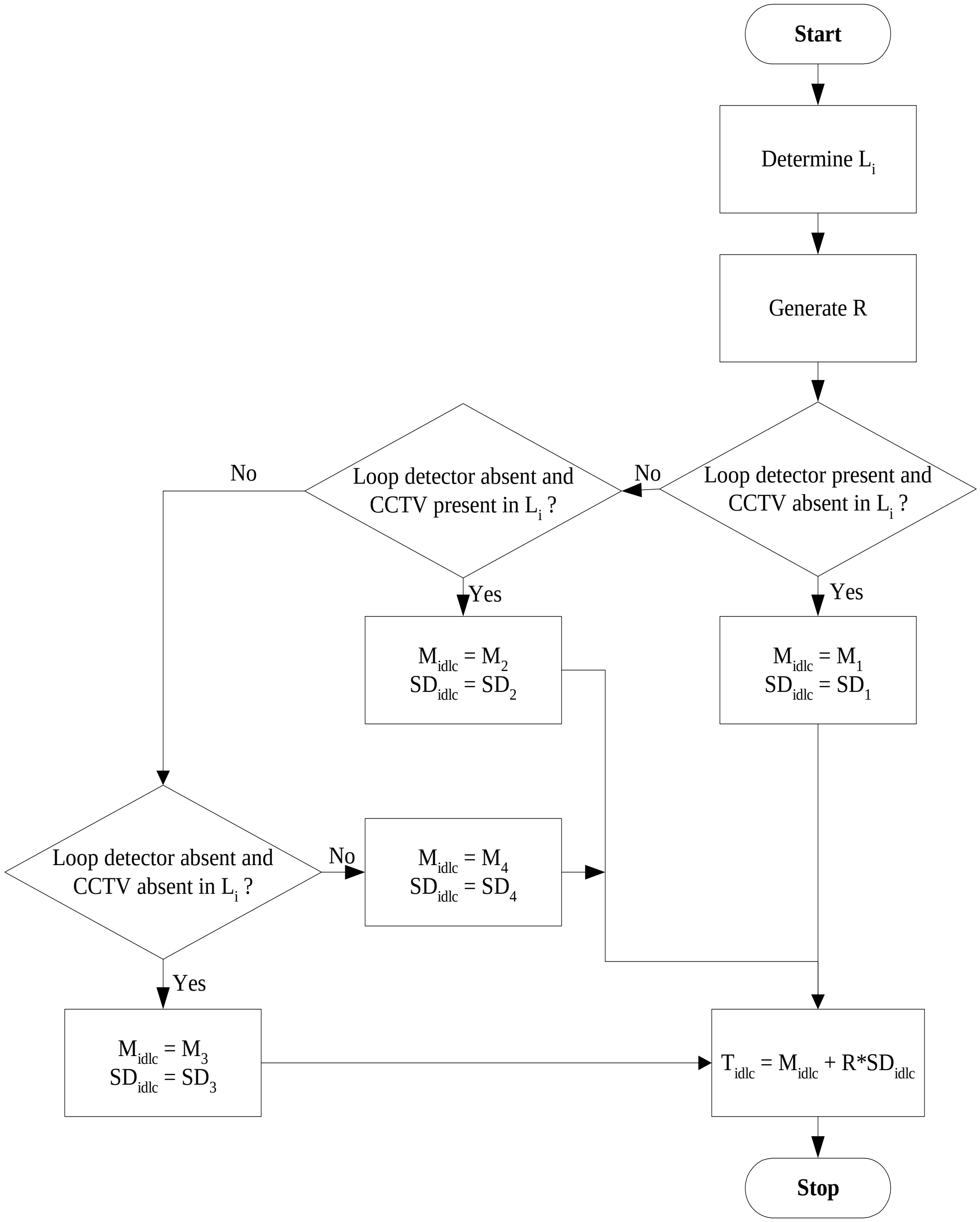


Figure 31. Flow-chart for the implementation of incident detection by loop detectors and CCTVs

Following is a copy of the C++ code written to implement the function *return_det_time:*

```
/*
 * return_det_time
 *
 * ACCESS: public
 *
 * computes the detection times of incidents based on Loop detector and CCTV
   data
 *
 * PARAMETERS: link index (i)
 * RETURN TYPE: incident detection time (detection_time)
 *
 * EDITED: (DATE AUTHOR DESC)
 * 05/23/02  Gaurav Jaiswal  initial version
 */
float sim::return_det_time(int i)
{
      /*variable declarations*/
      float detection_time = 0;                                        (1)
      float rand_num1 = 0;                                             (2)
      float rand_num2 = 0;                                             (3)

      /*generate random number between -1 and 1 to provide a variance in the
        detection times returned by the function*/
      rand_num1 = (float) rand()/RAND_MAX;                             (4)
      rand_num2 = (float) rand()/RAND_MAX;                             (5)
      if(rand_num1 <= rand_num2)                                       (6)
            rand_num1 = -1*rand_num1;                                  (7)

      /* compute the detection time (detection_time) based on the loop
         detector and CCTV data provided in the input file*/
```

Figure 32. C++ code of incident detection by loop detectors and CCTVs

The objective of the function is to return the detection time for a particular incident, based on the availability of *Loop Detectors and CCTVs* in the link in which incident occurred (L_i).

link_data_main is a two dimensional array used in the model to store link characteristics. The following data was taken as input from the link file

- link_data_main[i][13]
- link_data_main[i][14]

Table 26. Rules for input data for Loop detectors

link_data_main[i][13]	Comment
1	Loop detector present in the link
0	No Loop detector present in the link

Table 27. Rules for input data for CCTVs

link_data_main[I][14]	Comment
1	CCTV present in the link
0	No CCTV present in the link

Table 28. Incident detection times based on loop detector and CCTV data of a link (conversation with Mark Smith, NJDOT, January 22,2003)

Loop detector	**CCTV**	**Detection time (minutes)**	
		Mean	**Variance**
Present	Not Present	3	0.5
Not Present	Present	1.5	0.5
Not Present	Not Present	10	1
Present	Present	1	0.5

Incident Detection Using Cellular Phones: It has been noted that the growth of cellular telephone popularity has resulted in that becoming the most important detection technology in most metropolitan areas. The literature review on the efficiency of cellular call-in programs also showed that these programs have been very effective.

Following is a flow-chart explaining the logic of the module (*return_det_time_cellphones)* generating incident detection times based on cellular phone calls made by travelers:

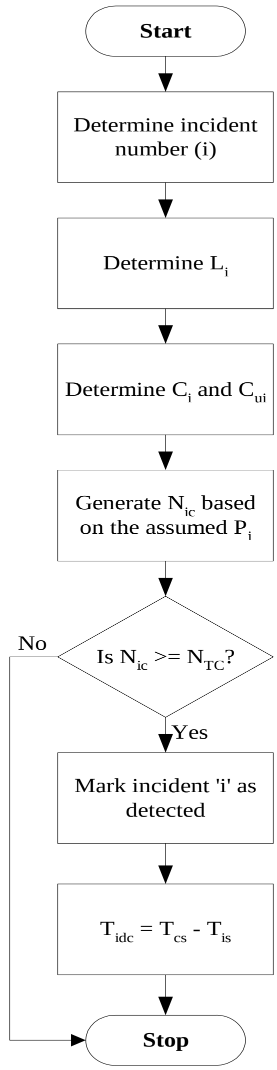


Figure 33. Flow-chart for the implementation of incident detection by cellular phone calls made by travelers

```
/*
 * return_det_time_cellphones
 * ACCESS: public
 * computes the detection times of incidents based on cellular phone calls
   made by travelers
 * PARAMETERS: incident index (i)
 * EDITED: (DATE AUTHOR DESC)
 * 05/23/02  Gaurav Jaiswal  initial version
 */
void sim::return_det_time_cellphones(int i)
{
      /*variable declarations*/
      int end_var = 0;                                                (1)
      int temp = inc_detail[i][1]-1;                                  (2)

      /*find the link number in which the incident occurred*/
      temp = cell_prop[temp][0] - 1;                                  (3)

      /*find cell number in which the incident occurred and it's
        preceding cell*/
      if(first_last_cell[temp][0] == inc_detail[i][1])                (4)
      {                                                               (5)
            temp = inc_detail[i][1]-1;                                (6)
            end_var = temp;                                           (7)
      }                                                               (8)
      else                                                            (9)
      {                                                               (10)
            temp = inc_detail[i][1]-1;                                (11)
            end_var = temp - 1;                                       (12)
      }                                                               (13)

      /*generate cellular phone calls made by the travelers present in
        the incident cell and one cell ahead of it, if the number of
        calls exceed the threshold value, assume incident to be verified*/
      for(int j = temp; j >= end_var; j--)                            (14)
```

Figure 34. C++ code of incident detection by cellular phone calls made by traveler

The objective of this function is to compute the detection time for a particular incident based on the phone calls made by travelers from their cellular phones about the occurrence of an incident on a link. Instead of using mean and standard deviation for computing the incident detection time based on cellular phones, a different logic was implemented. The program used two input parameters namely, percentage of cellular phone owners among travelers and Random cellular calls were generated by the program for the travelers that were on the incident link during the duration of the incident.

When the total number of calls generated exceeded the predetermined threshold number of calls, the incident was assumed to be detected and verified, and the detection time was stored.

The information read from the parameter file includes:

- Percentage of cellular phone owners among the travelers
- Threshold number of calls received by the Traffic Management Center (TMC) after which incident is assumed to be verified and incident response units are dispatched to the incident scene

Effects of Variable Message Signs (VMS) on Traffic flow

The first step of incident response is the deployment of requested resources to the incident. The process includes generating a response plan and dispatching resources and responses by various organizations. The effectiveness of incident response depends on the speed of communication and decision-making, organizational readiness, placement of resources, and travel time to the scene.

For major incidents, incident response can occur in stages, where different resources are dispatched for different phases of the clearance process.
The traffic simulation model focuses on the effects of VMS. VMS are also known as Dynamic Message Signs (DMS) or Changeable Message Signs (CMS). VMS's can be used by operating agencies to disseminate travel information on a near real-time basis. VMS's are among the most flexible and powerful means of

communicating with motorists on the road. Both fixed-location and portable VMS's are used to support incident management functions. The messages presented can be operated on a fixed-time basis, via on-site controls (as in an incident), or remotely, via a connection with a traffic control center. VMSs are most often used to:

1. Inform motorists of varying traffic, roadway, and environmental conditions (including variable speed limits in adverse conditions)
2. Provide specific information regarding the location and expected duration of incident related delays
3. Suggest alternate routes because of construction or a roadway closure
4. Redirect diverted drivers back onto the freeway

Following is a flow-chart explaining the logic of the module implementing incident response using VMS in the program:

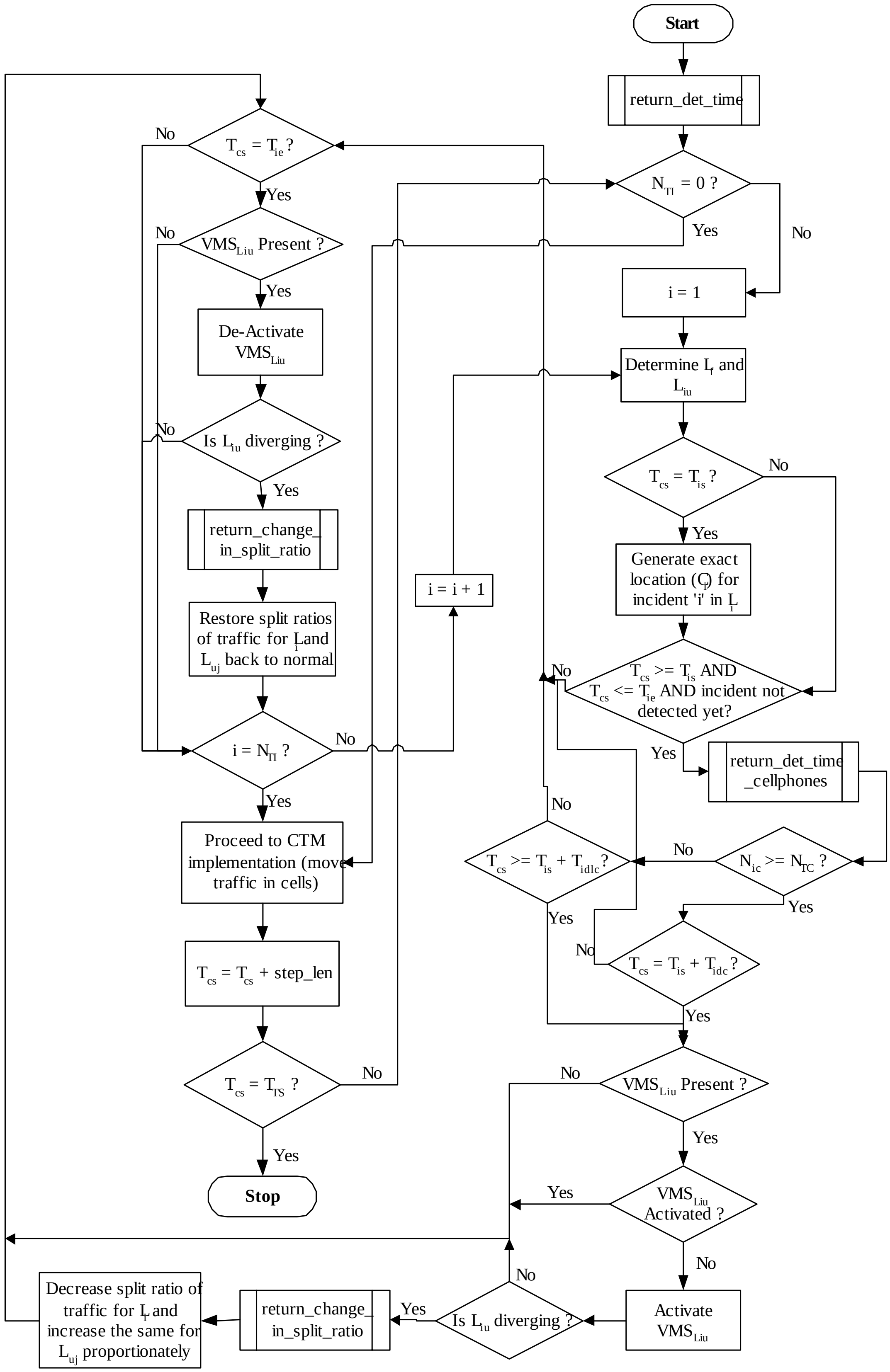


Figure 35. Flow-chart for computer implementation of VMS

```
/*if current simulation time is more than the incident start time and
  less than the incident end time then do the following*/
if(time_index >= inc_detail[h][3] && time_index <= inc_detail[h][4]) (1)
{                                                                    (2)
      if(inc_detail[h][5] == 0)                                      (3)
      {                                                              (4)
            /*if current simulation time is more than the summation of
              incident start time and incident detection time using loop
              detector and CCTV and incident has not been detected yet
              then call vms_diversion function to change the split
              ratios of the following links*/
            if(time_index >= (inc_detail[h][3] + loop_cctv_det_time[h])
            && vms_activated[h] == 0)                                (5)
                  vms_diversion(h);                                  (6)
       }                                                             (7)
      else                                                           (8)
      {                                                              (9)
            /*if current simulation time is equal to the summation of
              incident start time and incident detection time by
              cellular phone calls and incident has not been detected
              yet then call vms_diversion function to change the split
              ratios of the following links*/
```

Figure 36. C++ code for VMS implementation

The implementation of incident response using VMS in the simulation model involves several functions and additional codes that have not been displayed here due to size limitations. However, the logic of implementation can be easily understood from the flow-chart shown in Figure 35.

The following data was taken as input from the link file

- link_data_main[i][12]

Table 29. Rules for input data for VMS

link_data_main[i][12]	Comment
1	VMS present in the link
0	No VMS present in the link

The information read from the parameter file include the proportion of the split ratios of traffic going in the following links of a diverging link that remains in the event of an incident occurrence in one of the following links.

If there is a decrease in the split ratio for an incident link of a diverging link, then there is a corresponding increase in the split ratio of the other following links of that diverging link and the increase is distributed equally among them. An estimate of the percentage reduction in link capacities in the event of an incident is shown in Table 30 [(37)].

Table 30. Percentage of original link capacity remaining for incidents of type accidents and debris [(37)]

Incident Location	4+ Lanes	3 Lanes	2 Lanes	1 Lane
Median shoulder	74.0	69.0	64.0	59.0
Right shoulder	85.0	83.0	81.0	79.0
1 lane blocked	82.0	53.0	39.0	0.0
2 lane blocked	26.7	18.4	0.0	
3 lanes blocked	13.9	0.0		
4 lanes blocked	0.0			

Following are the assumptions made about the computer implementation of VMS in the program:

1. VMS is located at the upstream link of the incident link
2. VMS is not activated when the incident occurs, it gets activated only when the incident is detected and verified either by the data from loop detector and CCTV or from the cellular phone calls made by travelers.

Incident Response Module

The previous section described basic incident detection functions along with the VMS simulation capabilities. However, it's important to model complex process involved in incident response after incident detection and verification. Thus, in this section, the implementation of the complex incident response features is disccussed.

Incident response simulation is the critical component of the entire simulation system, which activate and terminate traffic simulation at the right time, read the output information, monitor the status of each incident under restoration, update the status of incidents in the waiting list, maintain the location and the status of each service vehicle, operating the patrolling services. Before presenting the flow of this simulation module from the perspective of the model development, the notation used in the following sections is presented below.

t_0: Time of occurrence of the incident (seconds).

t_D: Detection time of the incident (seconds).

t_{D2}: Time period that the incident is detected by FSP (seconds).

l: Location of the incident (node number).

i: Index number of incidents.

j, k: Index number of patrolling routes.

m, n: Index number of depots.

pt: Travel time of the FSP vehicle to the site of the incident along the given patrolling route (seconds).

dt: Travel time of the service vehicle dispatched from the depot to the site of the incident (seconds).

D: The set of the depots.

Ω**:** Set of the patrolling routes.

Ψ**:** Set of the depots.

For each incident i, its location, time of occurrence (t_0), severity level, and the number of required service units are known from the results of incident generation module. The initial detection time, t_D, is generated in accordance with a normal distribution. The reason the term “initial” is used is that the actual detection time could be shorter if an FSP vehicle finds the incident. With this information at hand, the clearance time of this incident is described as follows.

First, it needs to be checked if this incident is located on one of the patrolling route. If this incident occurred in an area where there are multiple patrolling routes, the service vehicle on one of the patrolling routes is chosen to respond this incident. The scheduled patrolling route should meet the following conditions: (1) this patrolling route is active. (2) the service vehicle assigned to this patrolling route will find the incident in a shorter time, t_{D2}.

Second, if the incident does occur on a patrolling route and it is faster to respond incident by a FSP vehicle than dispatching a service unit from the depot, then the FSP is assigned to the incident, which is described in the flowchart in Figure 37, “Incident response in patrolling service”.

Third, if there are not enough FSP service vehicles available for the specific incident, then t_D is replaced with t_{D2} and turn to the service vehicles assigned to the depot.

Finally, no FSP service vehicles respond to the incident, if: (1) the location of the incident does not belong to any patrolling route. (2) the location of the incident belong to a patrolling route which is not active. (3) the incident does belong to a patrolling route, but it will be slower to than clearing it by the service vehicle dispatched from the depot. In this case, service vehicles need to be sent from the depot at time t_0+t_D. Figure 37 illustrates the steps listed above.

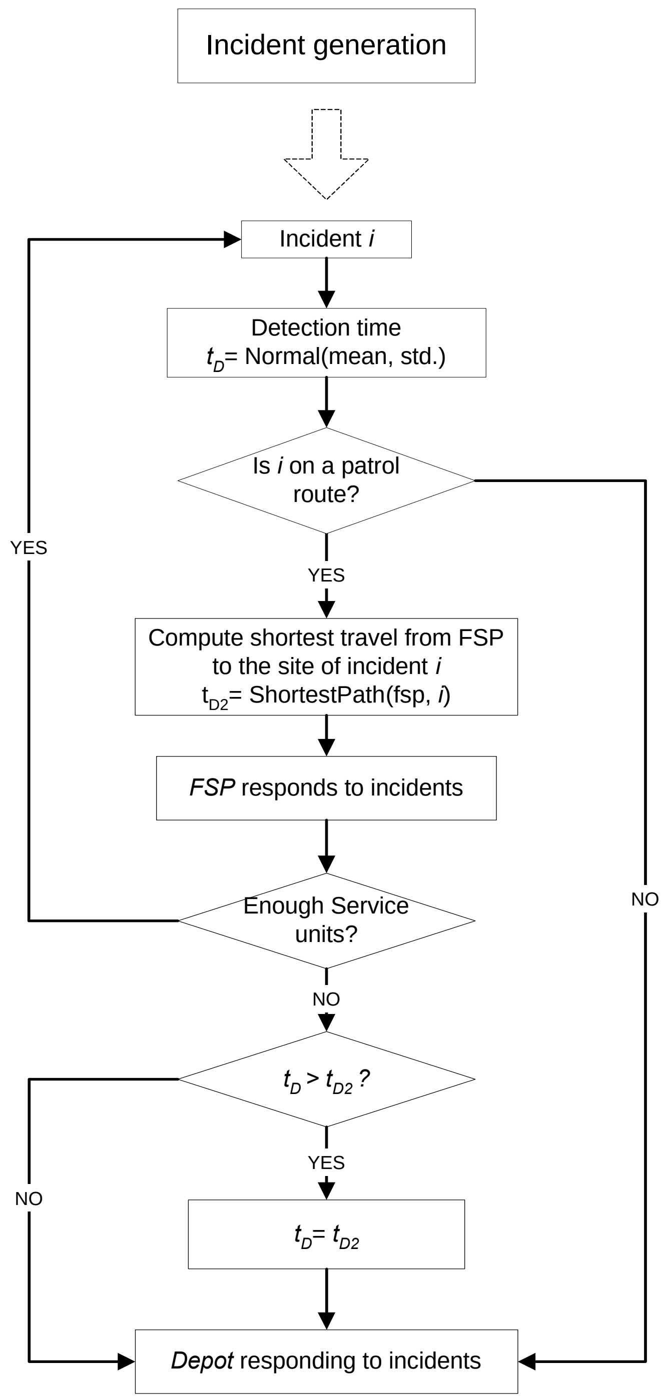


Figure 37. Flowchart of the incident response

Dispatching policy

Whenever more than one incident is on the waiting list, the dispatching center needs to decide which service vehicle should be dispatched to respond to which incident. Two dispatching policies are widely used: namely, FCFS and NN.

Patrolling service

Whenever there is an incident detected, it is first checked if this incident is on any enabled patrolling service route. If it is, then the distance is compared from the current location of the patrolling vehicle and the nearest depot to the site of the incident. If the patrolling service vehicle is closer and enough for the restoration, there is no need to dispatch extra service vehicles from the depots. Otherwise, all or part of the requested service vehicles need to be dispatched from the depots. A double linked list is used to define the patrolling routes (See Double Linked List For Patrolling Route section)

When a new simulation replication begins, the patrolling service vehicles always set out from the starting (head) node and keep moving along the patrolling route until they run into an incident. Then, the patrolling vehicles will stop at the site of the incident and stay some time there to assist the incident clearance. The clearance time depends on the incident properties. The time when the patrolling vehicle finishes the task and resuming the patrolling, t_0, and the site of the incident it just served, x_0 are both recorded. Based on this information, the location of the patrolling vehicle at any time t can be calculated:

$$\textit{The distance from } x_0 = (\textit{patrolling speed}) \times (t - t_0)$$

The patrolling speed is assumed equal to the average traffic speed by assumption, which is collected from the results of traffic simulation model for each link. After it finishes its task, the patrolling vehicle resumes the patrolling route until it comes across another incident. Before the description of work flow of FSP in detail, it is worth to restate the conditions which the incident to be cleared by the FSP should satisfy: The incident should be located on one of the active patrolling routes, i.e., there exists a patrolling route j, such that, *GetTheNode(j, l)* = *True* & *IsActive()* = *True*.

The flow chart depicted in Figure 38 illustrates the incident response procedure in the patrolling service:

(1) If there are multiple patrolling routes that satisfy above conditions, without loss of generality, the set of these patrolling routes are assumed as Ω.

(2) Get the current location of the service vehicle assigned to patrolling route j, $\forall j \in \Omega$

(3) Compute the shortest travel time, pt_j, for the service vehicle on patrolling route j to the incident site l, $\forall j \in \Omega$

(4) Pick the patrolling route, k, with shortest travel time among Ω, i.e., $k = argmin\{pt_j\}$, and let $t_{D2} = pt_k$. Remove k from Ω.

(5) If Ω is empty, then replace t_D with t_{D2}, if $t_D > t_{D2}$, the clearance of the incident should be handled by vehicles in the depot, which is depicted in Figure 39, "Flow chart of the simulation logic used to model operations of service vehicles dispatched from depots".

(6) Update the status of patrolling route k, which includes: (i) the location of the service unit, (ii) the time when the service vehicle finishes its task.

(7) If the number of service vehicles from the patrolling route k cannot meet the requirement of the incident, then repeat steps (1) through (7).

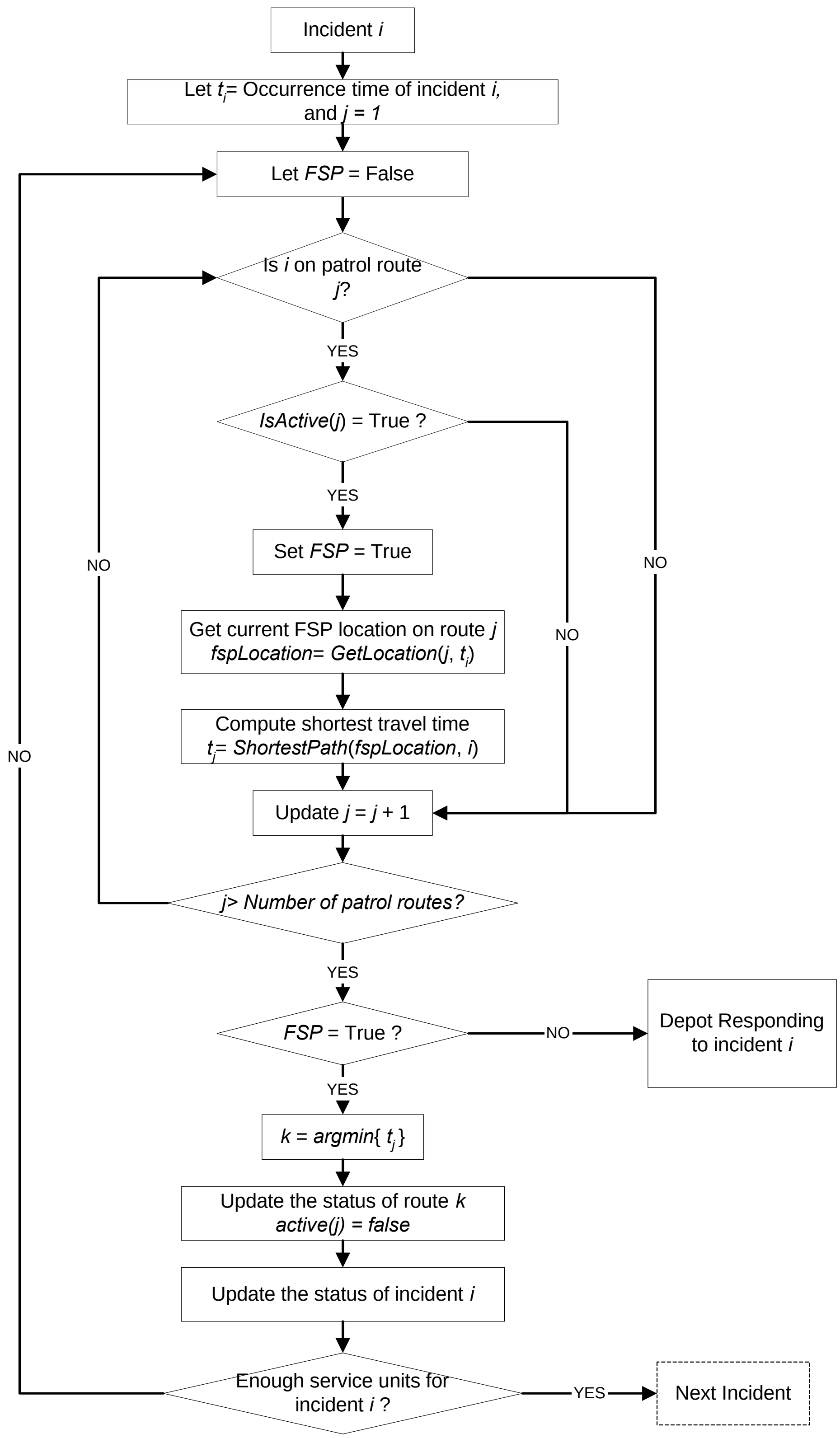


Figure 38. Flow chart of incident response in patrolling service

Depot

If only one type of service vehicles are considered or the fleet of service vehicles are considered as a single unit, then the response service originated from the depot can be described as follows:

(1) Refresh the status of the depots at time $t_0 + t_D$, gathering the following information: (i) the number of the idle service vehicles at each depot. (ii) the request of service vehicles by the incident. Note that the request might be smaller than the initial values, due to the response service of FSP.

(2) Choose the nearest depot with idle service vehicles. Let Ψ be the set of the depots, which have at least one idle service unit. Compute the shortest travel time, dt_m, from depot m to the incident site I, $\forall m \in \Psi$. Pick the depot, n, with shortest travel time among Ψ, i.e., $m = argmin\{dt_m\}$.

(3) Update the number of idle service vehicles at depot n, and the request of service vehicles by the incident.

(4) If the request of service vehicles by the incident is greater than 0, then repeat steps (1) through (3). Otherwise, compute the duration of the incident, then the whole response procedure moves to next incident.

The flow chart of this part is illustrated in Figure 39.

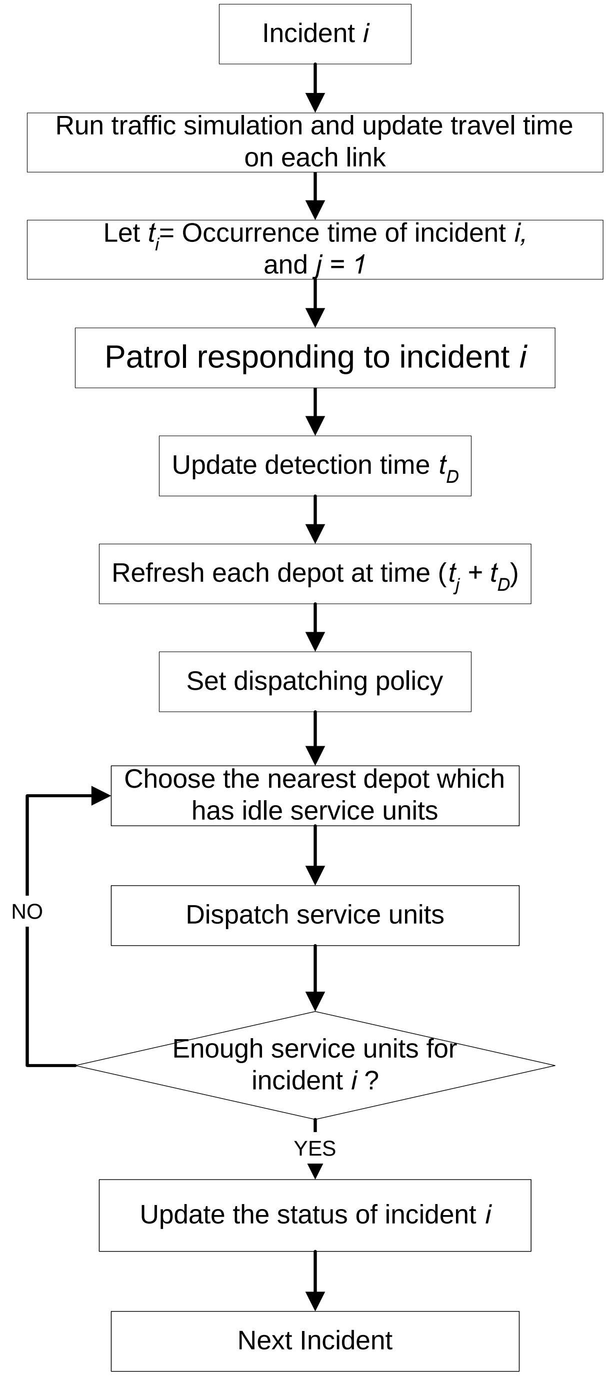


Figure 39. Flow chart of the simulation logic used to model operations of service vehicles dispatched from depots

Figure 40 and Figure 41 describe the incident response in a more realistic way, where five different types of service vehicles are considered (police cars, ambulances, tow trucks, fire trucks and EMS). The basic logic is same as the one shown in Figure 39. Some additional comments are:

(1) All other types of service vehicles, including ambulances, tow trucks, fire trucks and EMS, can only be dispatched after the arrival of the police car at the incident site.

(2) Tow trucks can only start to work after ambulances and fire trucks finish their work, if they are requested by the incident.

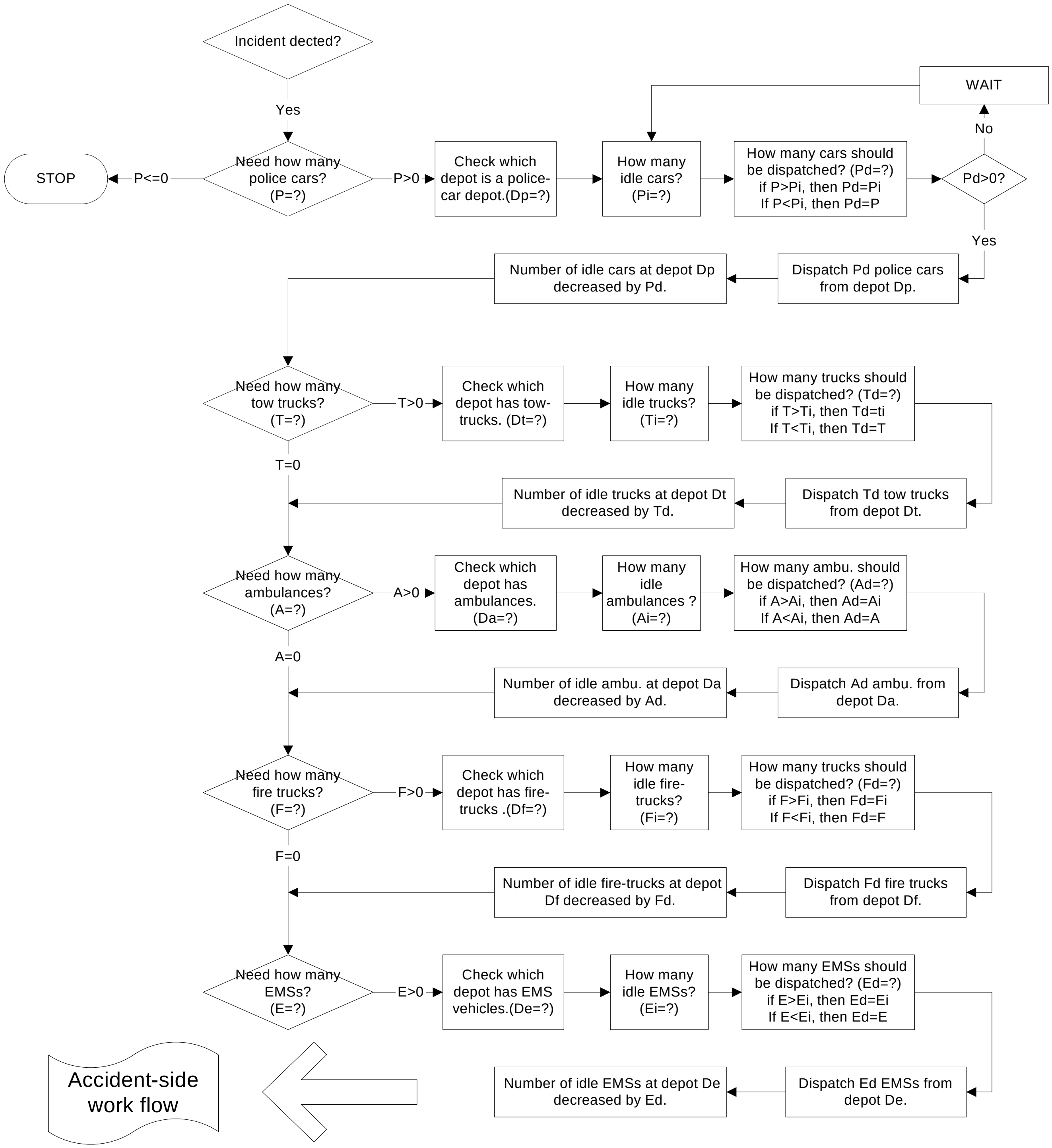


Figure 40. Flow chart of the simulation logic for various types of depots

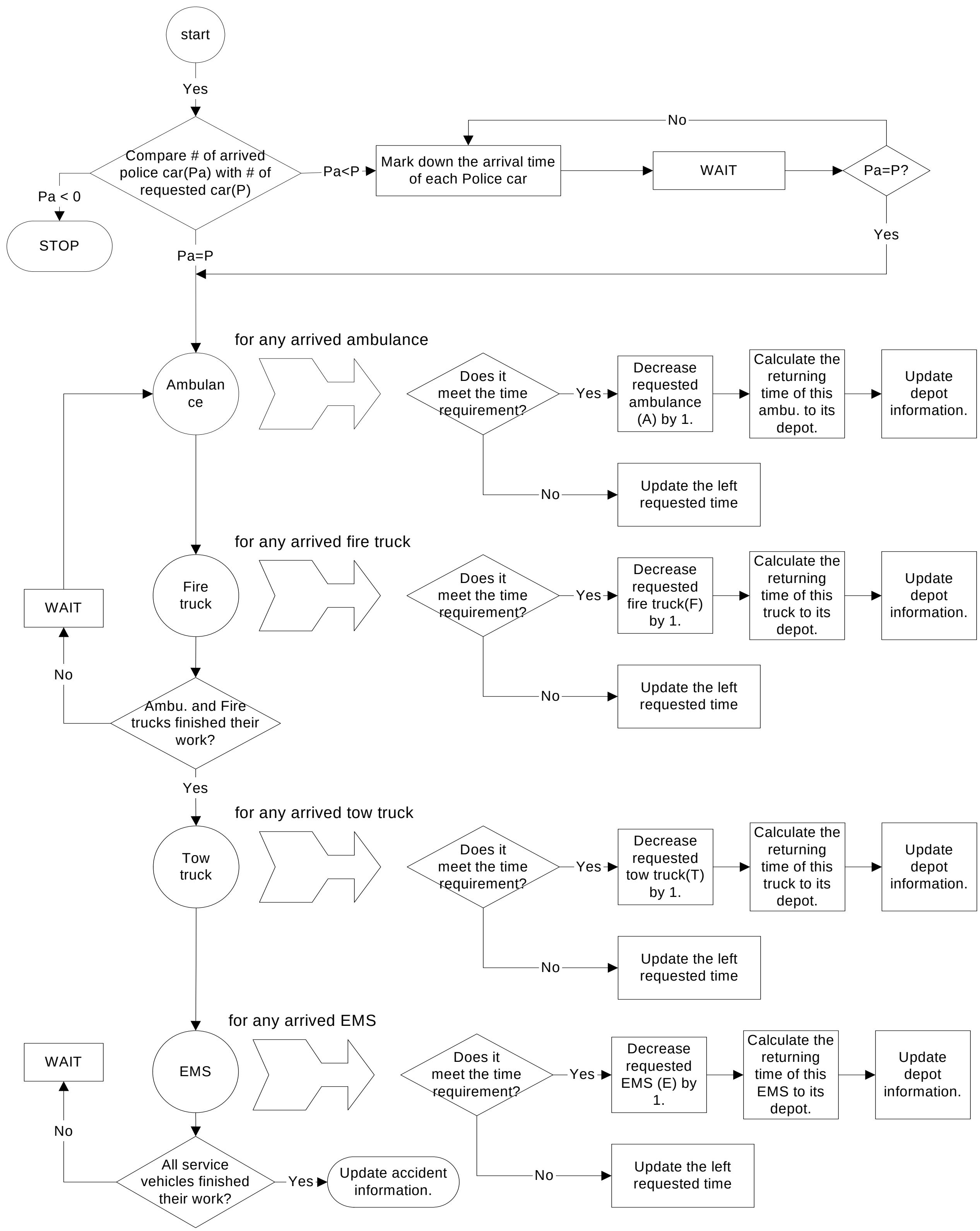


Figure 41. Flowchart for simulating the operations at the incident site

Database

Microsoft Access is a database tool developed for the PC environment, which is very appropriate for small database applications. In this simulation application, an Access database is constructed to save important output information of the simulation process, which makes future reference convenient and fast. The historical incident data is also stored in this database for the purpose of incident generation.

Status of Incidents

The initially generated incident properties are written into the *Accdents* table, and the program keeps updating the status of each incident for each replication. The structure of this Table 31 is shown below.

Table 31. Structure of Accidents table

Field name	***Description***
ID	The identification of this incident
Replication	The incident is generated in which replication.
DetectedTime	The detection time of the incident. Generated randomly or get it from database, depending on which option the user chooses.
Location	The location of the incident
Priority	The priority level of the incident
FinishTime	The time when the incident is cleared, which is updated by the program.
Status	0-not cleared; 1-cleared. Updated by the program.
PoliceCars	The number of police cars need to be onsite.
PWorkLoad	How long need a police car stay onsite.
TowTrucks	The number of tow trucks requested by the incident.
TWorkLoad	How long need a tow truck to be onsite.
Ambulances	The number of ambulances requested by the incident.
AWorkLoad	How long need an ambulance to be onsite.
FireTrucks	The number of fire trucks requested by the incident.
FWorkLoad	How long need a fire truck to be onsite.
EMSs	The number of EMS vehicles requested by the incident.
EWorkLoad	How long need an EMS vehicle to be onsite.

Activities of Depots

The detailed activities of depots are saved in each simulation replication for further analysis or double check. The structure of the data table (Table 32) is shown below.

Table 32. Structure of DepotActivity table

Field name	***Description***
ID	The identification of this incident
Replication	This activity is in which replication.
DepotName	The name of this depot.
DepotID	The ID of this depot.
WhichTFRU	Which service vehicle of this depot is assigned to a task.
ActivityIndex	The identification number of this activity.
ToWhere	Where is this service vehicle dispatched to.
NotificationTime	The detection time of the incident which is responded by this activity.
DispatchTime	The time when this service vehicle is dispatched.
TravelTime	The traveling time from the depot to the site of the incident.
ReturnTime	The time when the dispatched vehicle returned to the depot.

Historical Incident Data

In the second method to generate incidents in the incident response simulation, the incident data of the year 2000 are used as the template for incident generation. The useful information for incident generation of the historical data is listed below.

Table 33. Historical incident data

Field name	***Description***
Record_no	The record number
ROUTE	The route where the incident occur.
START_MP	The starting milepost of the site of the incident.
END_MP	The ending milepost of the site of the incident.
INPUT_DATE	The input data of this record.
LANES_CLOSED	The number of closed lanes.
LANES_OPEN	The number of open lanes.
Final_Duration	The duration of the incident.

ROUTE and *START_MP* in the above Table 33and the information provided in table *LINKS* (Table 25) mentioned earlier are used to determine the location of the incident in the mathematical description of the roadway network. All the incidents with *INPUT_DATE* same as the randomly generated date will be picked out as the incidents for that replication. *LANES_CLOSED* and *LANES_OPEN* are used to calculate the severity level of the incident, while the workload of each requested service vehicle is estimated based on *FINAL_DURATION*.

C ++ Implementation of Incident Management Simulation Model

The detailed list of the main C++ classes is given in Appendix C.

Data Structures

Double Linked List For Patrolling Route

To implement the simulation of patrolling service, a double linked list (Figure 42) is used to describe the patrolling route. Each node of this list has two pointers, with “next” pointing to its next node and “previous” pointing to its previous node. The node with null value of “previous” pointer is the head node, while the node with null “next” pointer is the tail. When a simulation starts, the patrolling fleet always sets out from the head node and moves along the linked list. Whenever it hits the tail or the head, the patrolling vehicle reverses its direction and keeps moving until it runs into an incident.

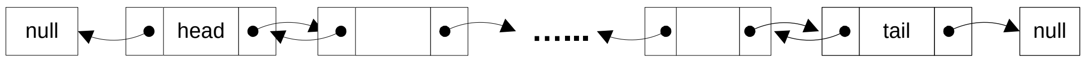


Figure 42. The double linked list

The double linked list is implemented for the patrolling routes as below, where *nNode* is the index number of this node, *pNext* is the pointer pointing to its downstream node, *pPre* is the pointer to its upstream node, *travelTime* represents the time needed to move from node pointed by *pPre* to this node.

```
typedef struct _Node{
        int nNode;
        int travelTime;
        _Node * pNext;
        _Node * pPre;
}NODE;
```

Array for Incident Information

To improve the simulation time efficiency, an array called *MatrixInc* is created to store the incident information for each simulation replication instead of querying the database. The memory size limit should not be a problem, because the number of incidents in a replication cannot be very large. Actually, four or five incidents in a single replication is often the case. *MatrixInc[i][j]* represents the *j*th property value of the *i*th incident. For each incident, there are 15 properties, which are listed in the following Table 34.

Table 34. Information stored for each incident in matrixInc array

Field	Name	Possible value
0	Time of occurrence.	Integer (in seconds)
1	Location	Integer(node or link number)
2	Priority level	1~7
3	When this incident is cleared	
4	Status	0 (waiting) and 1 (cleared)
5	Number of police cars.	>= 0
6	Workload (time) of the police car.	
7	Number of tow trucks.	>= 0
8	Workload (time) of the tow truck.	
9	Number of ambulances.	>= 0
10	Workload (time) of the ambulances.	
11	Number of fire trucks.	>= 0
12	Workload (time) of the fire trucks.	
13	Number of EMS vehicles.	>= 0
14	Workload (time) of the EMS.	

Shortest-Path Algorithm

Figure 43 illustrates the shortest-path algorithm used in this simulation program. Label correcting algorithm finds the shortest path from a node (origin) to all other nodes. The algorithm is briefly described here:

- Initialization:

Let $I_i = \mathrm{M}$, $p_i = 0$, $L_o = 0$

Put the origin node (Node 0) in S_i, the sequence list

- Step 1: Optimality Test

If S_i is empty, terminate the algorithm, and make all labels permanent. The labels represent the shortest path costs from the origin to the corresponding nodes, and the predecessor labels can be used to trace the shortest path.

If S_i is not empty, continue with Step 2.

- Step 2:

Pick a node from S_i

Make the node “current node” and delete it from S_i

- Step 3:

Check every node that is accessible from the “current node:

If node j is accessible from node I and $I_i + t_{ij} < I_j$

Update the label for node j: $I_j =: I_i + t_{ij}$

Update the predecessor label: $p_j := i$

Put the node j in S_i

- Go to Step 1.

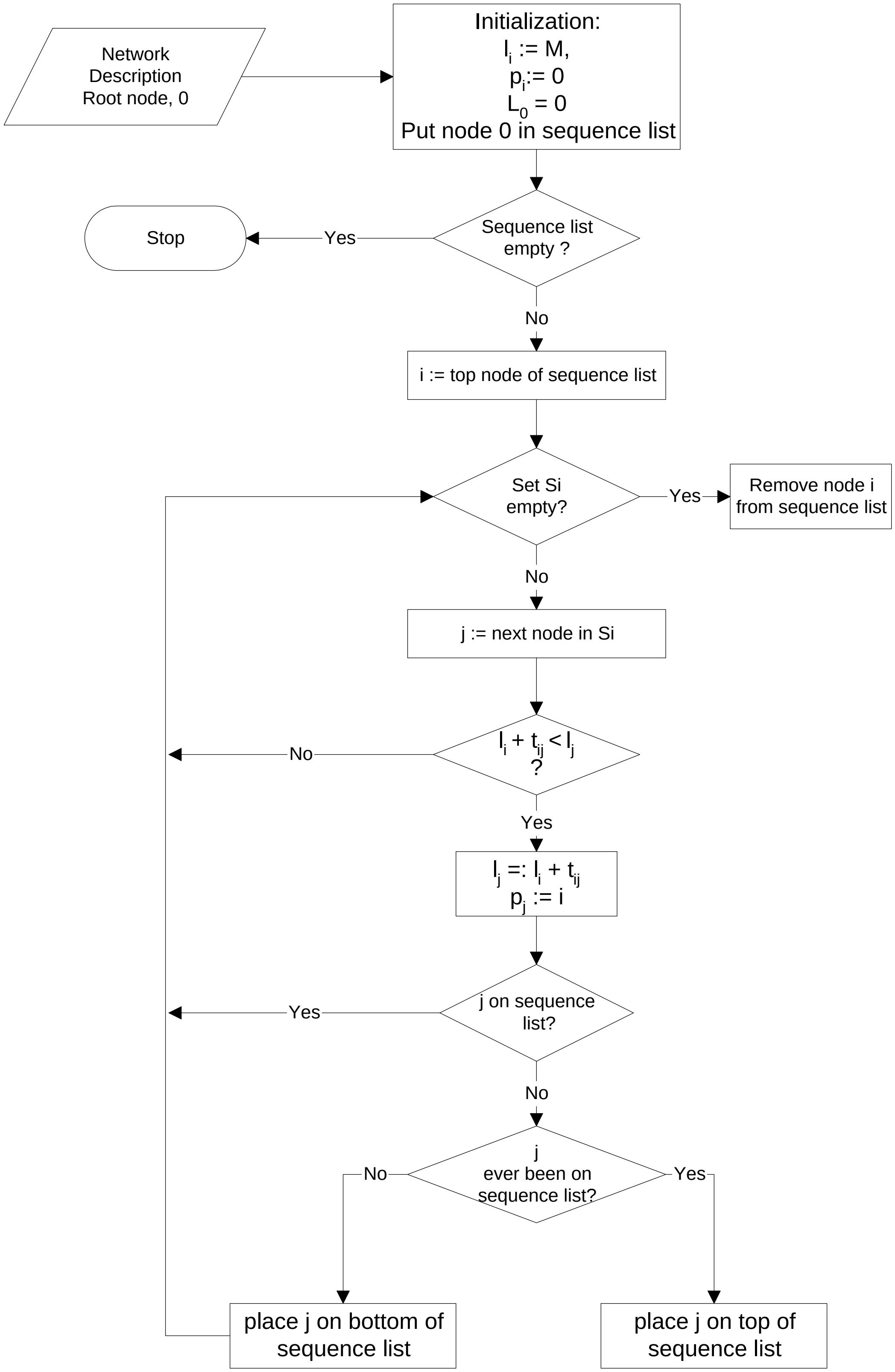


Figure 43. Label-correcting shortest-path algorithm

Evaluate Candidate Incident Management Strategies to be Applied in this Corridor

This chapter presents the results obtained by using the simulation model for the simplified South Jersey transportation network. The results for different scenarios are compared in terms of the link travel times and link vehicular densities.

Test Network

Figure 44 displays the South Jersey traffic network on which the developed simulation model is run, and Table 35 provides information about the route numbers that each link represents. There are five origin nodes and four destination nodes. Vehicles enter the network from the origin nodes, travel through the network, and finally leave the network from the destination nodes. The model uses a number of network characteristics such as free-flow speeds, jam densities, saturation flow rates, traffic demand etc. as input and generates output files for link travel times, link vehicular densities, link vehicle outflow, and incident detection times. All of the above mentioned input data is obtained from the ArcGIS database of the South Jersey network made available by NJDOT. The incident distributions are acquired from the incident databases also provided by NJDOT, and details about the distributions are discussed in previous chapters. Table 36 shows the traffic demand of the network. A sample of the input and output files along-with their respective descriptions can be found in Appendix D.

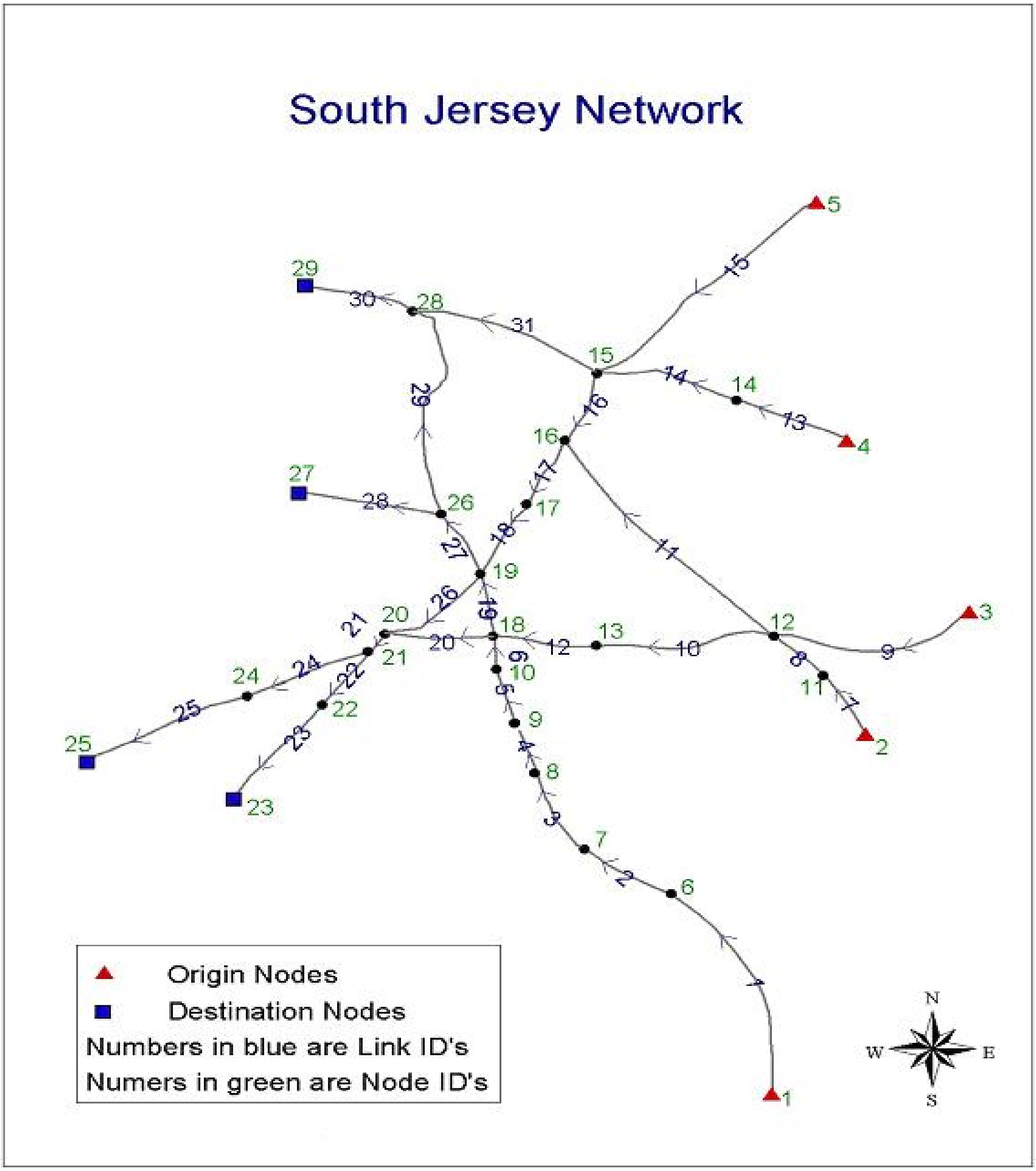


Figure 44. Link-node representation of South Jersey traffic network

Table 35. Route Description of the South Jersey Traffic Network

Route	Links
42	1, 2, 3, 4, 5, 6
76	19, 27, 28
676	29, 30
130	15, 17, 18, 21, 26, 22, 23
295	9, 10, 12, 20, 24, 25
30	7, 16, 8, 11
70	13, 14, 31

Table 36. O-D demand for the network for one-way traffic (veh/hr)

	Node 1	Node 2	Node 3	Node 4	Node 5
Node 6	2700				
Node 11		550			
Node 12			3000		
Node 14				1800	
Node 15					1100

A comparison is done between the travel time results obtained by running the simulation model with the actual South Jersey data without any incidents and the corresponding travel time information that is available in the ArcGIS database of the South Jersey network. Table 37 summarizes the results.

Table 37. Travel time Comparison

Route	Travel time from Simulation Model (secs.)	Travel time from GIS database (secs.)
42	556.58	606
76	241.91	282
130 (for links 15, 17 and 18)	652.36	581
295	742.80	840

Effects of Incidents on Traffic Flow

In this section, the effects of incidents on the traffic flow are demonstrated based on the simulation results on links 1 and 2. The jam densities and free flow travel times on these two links are shown in following tables (Table 38 and Table 39).

Table 38. Vehicular jam densities for link 1 and link 2

Link	Jam density (vehicles/mile)
1	432
2	432

Table 39. Free flow travel times for link 1 and link 2 - Scenario 1

Link	Free flow travel time (seconds)
1	225.82
2	73.31

<u>Scenario 1</u>

This scenario is designed to demonstrate the effect of an incident occurring on a link. It shows the results of two runs of the simulation model, where the first run has no incident on the chosen link (link 2) while the second run has an incident occurrence on the link.

Table 40. Incident details for link 2 – Scenario 1

Incident Link number	Number of lanes blocked	Total number of lanes	Start time (seconds)	End time (seconds)
2	2.0	3	600	1200

Link Travel Time

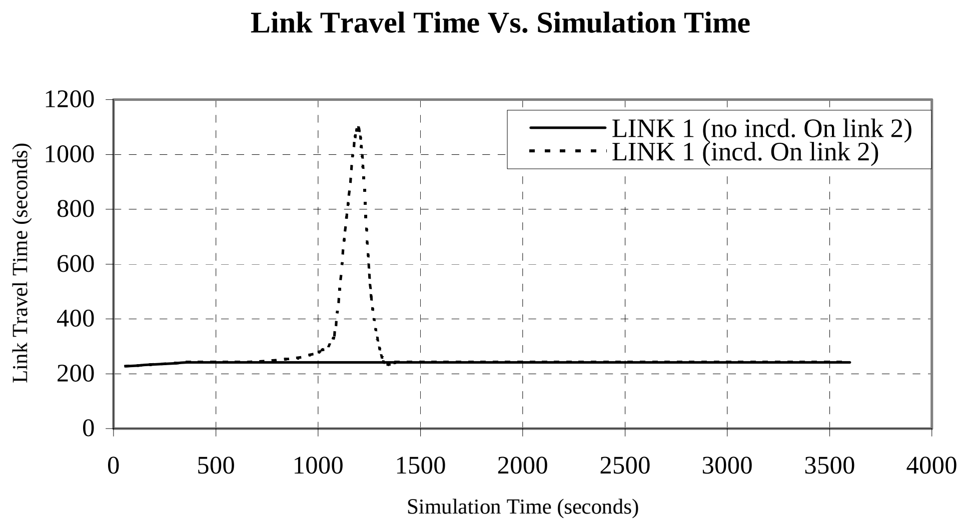


Figure 45. Comparison of travel times of link 1 for Scenario 1

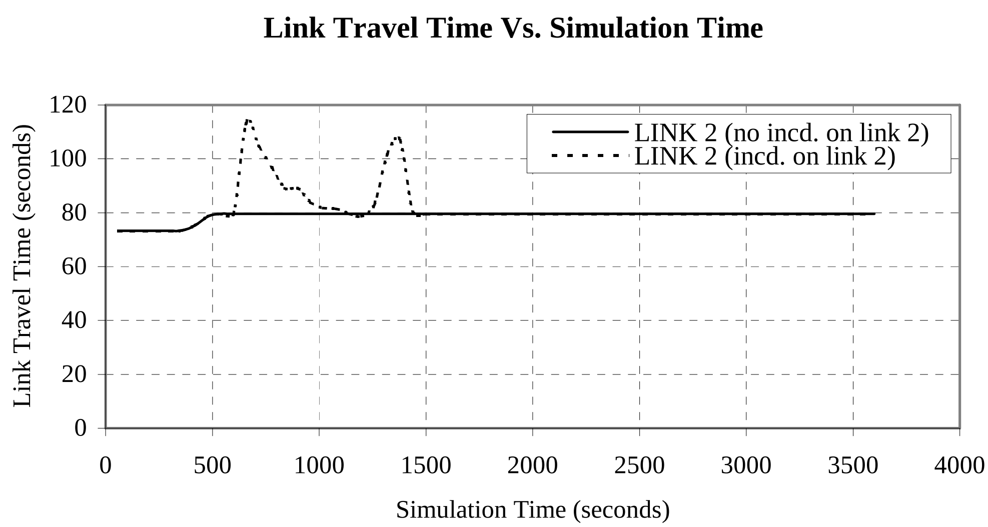


Figure 46. Comparison of travel times of link 2 for Scenario 1

It can be seen from the figures above that when there is no incident occurring on link 2, there are no sudden jumps in the travel time curves on both links 2 and 1. However, soon after the incident occurrence on link 2 at 600th seconds, a sudden and steady increase in the travel time of link 1 is noticed due to backward shockwave propagation (since link 1 is the upstream link of link 2). This increase in travel time in link 1 starts to drop down soon after the incident on link 2 is cleared (at 1200 seconds) and then the travel time returns to normal and merges with the no incident case.

Also on link 2, there is a sudden increase in the travel time after the incident occurrence due to the reduction in the capacity (and hence the average link speed) of link 2 caused by the incident. For link 2, the increase is not as sharp as compared to link 1 because soon after the incident occurrence on link 2, the vehicle outflow from link 1 into link 2 decreases (because of reduced capacity and saturation flow rate in link 2). However, the vehicles that are already almost at the end of link 2 are able to leave as they are unaffected by the incident occurring in the upstream of link 2, thus resulting in a decreased vehicular density in link 2 and hence a reduction in the travel time.

Another interesting fact can be observed from the travel time curve of link 2 as follows: immediately after the incident is cleared, there is again a small increase in the travel time of link 2, attributed to the fact that once the incident is cleared in link 2, the vehicles that are getting aggregated at the end of link 1 and waiting to get into link 2 since the incident started (at 600 seconds), are now allowed to enter link 2 (at 1200 seconds), thus causing a sudden increase in the vehicular density of link 2 and hence the increase in travel time.

Eventually, the travel time returns to normal and merges with the travel time curve for the no incident case.

Link Traffic Density

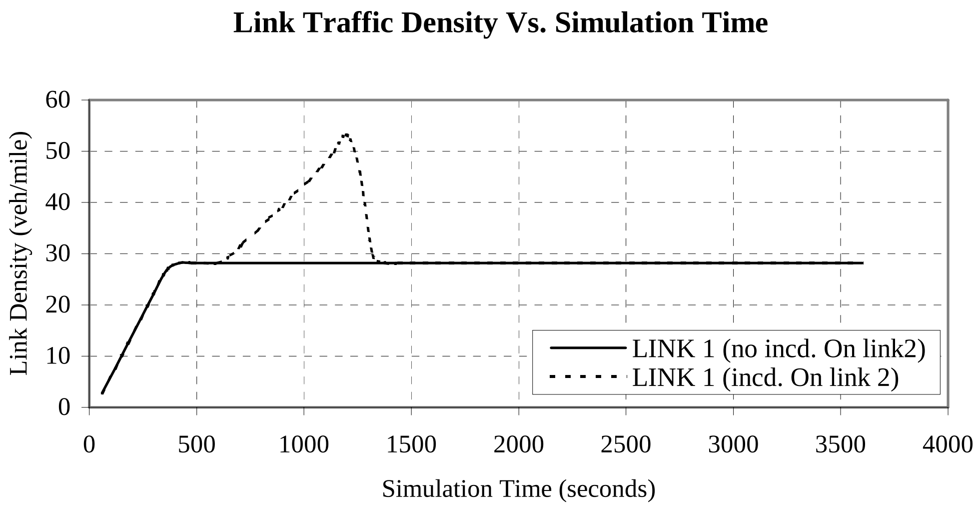


Figure 47. Comparison of vehicular link densities of link 1 for Scenario 1

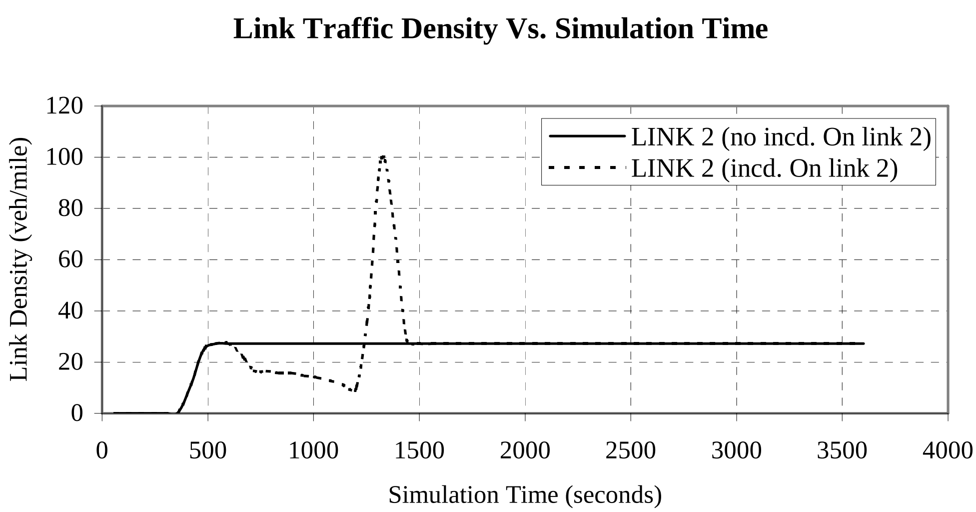


Figure 48. Comparison of vehicular link densities of link 2 for Scenario 1

Scenario 2

This scenario is designed to portray the impact of varying incident severity. It shows the results of two runs of the simulation model, with the first run having an incident of lower severity (one lane blocked) occurring on the chosen link (link 2), while the second run has an incident of higher severity (two lanes blocked).

Table 41. Details of the low severity incident

Incident Link number	Number of lanes blocked	Total number of lanes	Start time (seconds)	End time (seconds)
2	1.0	3	600	1200

Table 42. Details of the high severity incident

Incident Link number	Number of lanes blocked	Total number of lanes	Start time (seconds)	End time (seconds)
2	2.0	3	600	1200

Link Travel Time

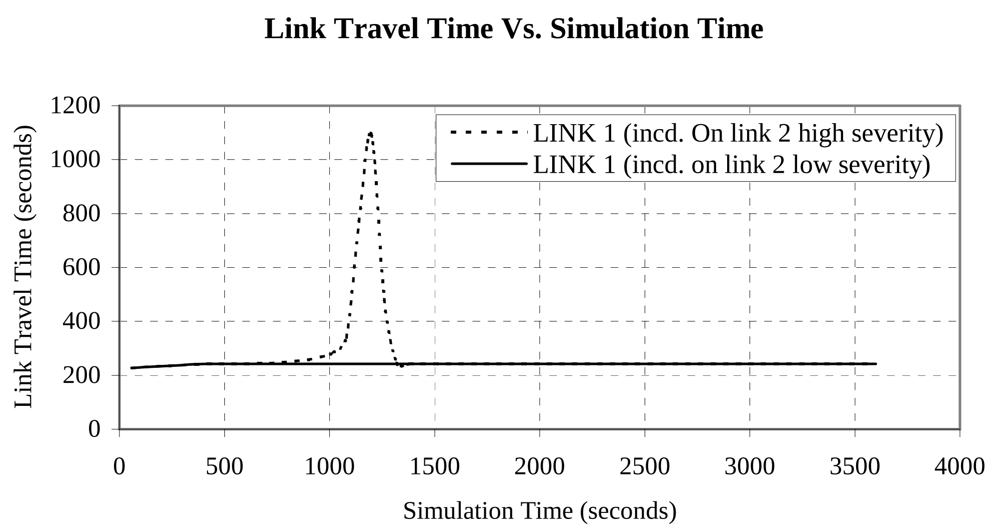


Figure 49. Comparison of travel times of link 1 for scenario 2

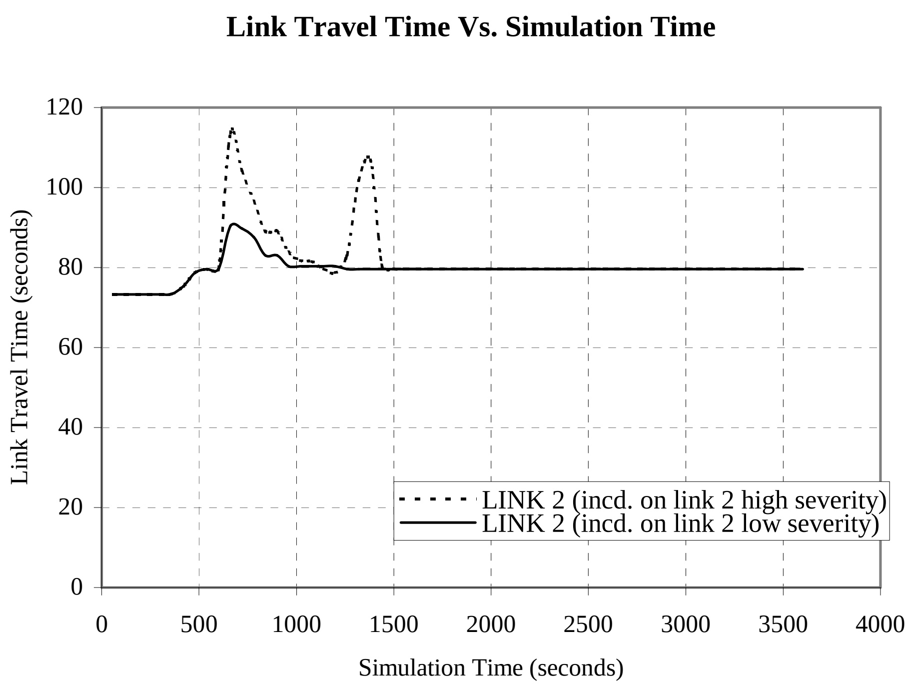


Figure 50. Comparison of travel times of link 2 for scenario 2

The trends in the travel time curve for link 1 for an incident of high severity has been explained in scenario 1. However, when the incident occurring on link 2 is not very severe, then there is very little increase in the travel time of link 1 because in the case of less severe incidents, the impact of the incident is almost entirely absorbed by the link in which it occurs and there is almost no backward shockwave propagation, unlike a more severe incident. This observation is however not strictly a rule because there are other factors which might also influence backward shockwave propagation, like the location of the incident (if the incident occurs at the end of the link, then there will be a backward shockwave propagation to the upstream link. This will be shown in the forthcoming scenarios). There is some increase in the travel time of link 2 during the incident duration, but this is less than what it is for the more severe incident. Also, since the incident is less severe, not many vehicles are stalled at the end of link 1 during the incident duration, explaining the fact that there are no sudden increases in the travel time curve for link 2 after the incident is cleared (i.e., there is no abrupt increase in the vehicles outflow of link 1 after incident clearance).

Link Traffic Density

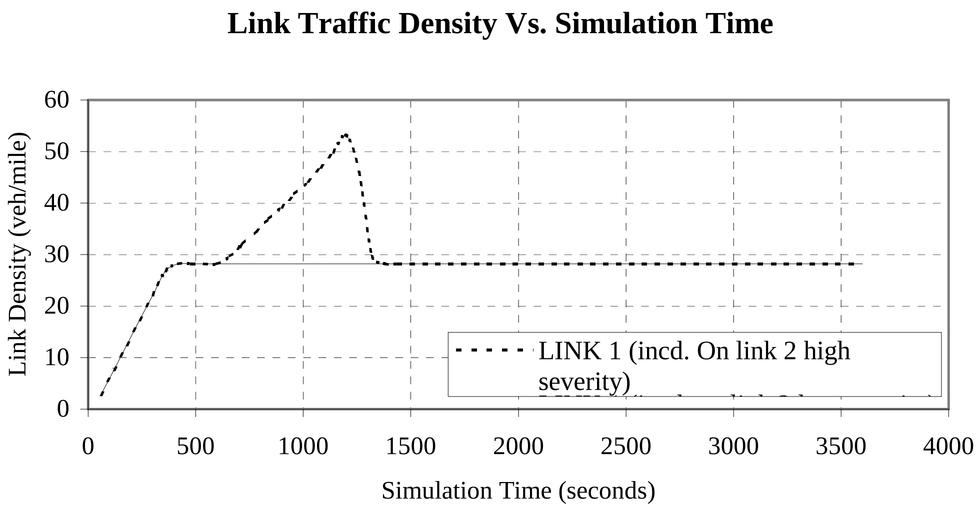


Figure 51. Comparison of vehicular link densities of link 1 for scenario 2

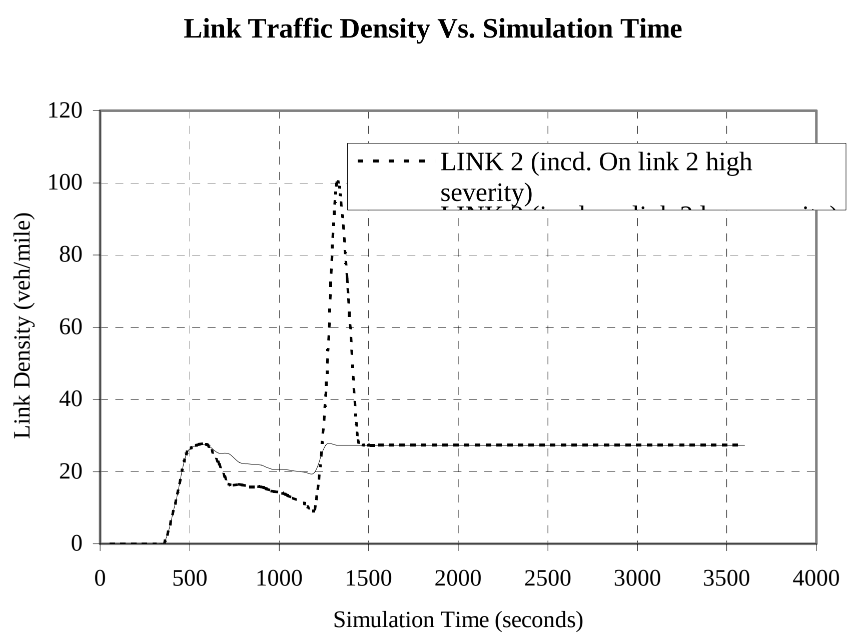


Figure 52. Comparison of vehicular link densities of link 2 for scenario 2

The trends in the link density curve for link 1 for an incident of high severity has been explained by scenario 1. However, when the incident in the downstream link is of low severity, then the density of link 1 does not increase too much compared to the increase in the case of a high severity incident. This is again attributed to the fact that for a less severe incident, there is almost no backward shockwave propagation in the upstream link of the incident link because almost the entire impact of the incident is absorbed by the incident link. Hence there is very little or no holding up of vehicles at the end of link 1 during the incident duration. Thus, the link density of link 1 remains almost the same.

For link 2, since the incident is not very severe, vehicles are not significantly jammed up in the downstream portion of link 1 during the incident duration because of the lack of backward shockwave propagation. Vehicles are able to leave link 1 and enter link 2, albeit at a slightly lower rate than compared to the no incident case and a slightly higher rate than the case with a more severe incident. This explains the higher link density of link 2 for a less severe incident as compared to that for a more severe incident during the time of the incident. However, the link density is definitely less than what it is when there is no incident on link 2. When the incident is cleared in the more severe incident case, there is a sudden surge in the number of vehicles leaving link 1 and entering link 2 due to the dissipation of the strong backward shockwave of link 1, and this caused a sharp increase in the link density of link 2 for some time after incident clearance. However, for a less severe incident case, there is no sudden jump in the link density of link 2 after incident clearance as the backward shockwave in link 1 is much less. Therefore, very little or no dissipation occurred after incident clearance.

Scenario 3

This scenario is designed to depict the impact of incident location. It shows results of two runs of the simulation model. The first run has an incident occurring at the beginning of link 2, whereas the second run has an incident occurring at the end of link 2. The location of incident occurrence can be controlled by varying the cell number of the incident link.

Table 43. Incident details for link 2 – Scenario 3

Incident Link number	Number of lanes blocked	Total number of lanes	Start time (seconds)	End time (seconds)
2	2.0	3	600	1200

Link Travel Time

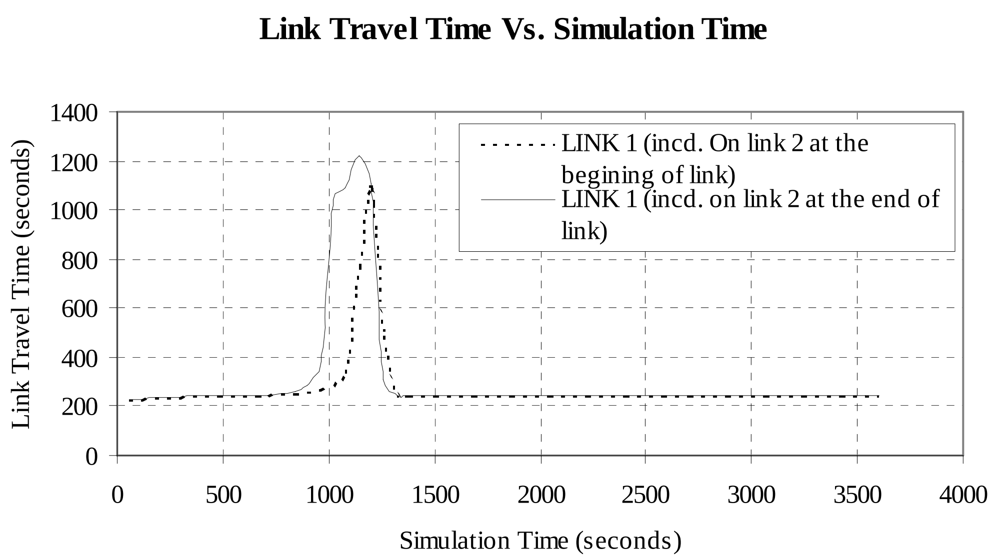


Figure 53. Comparison of travel times of link 1 for scenario 3

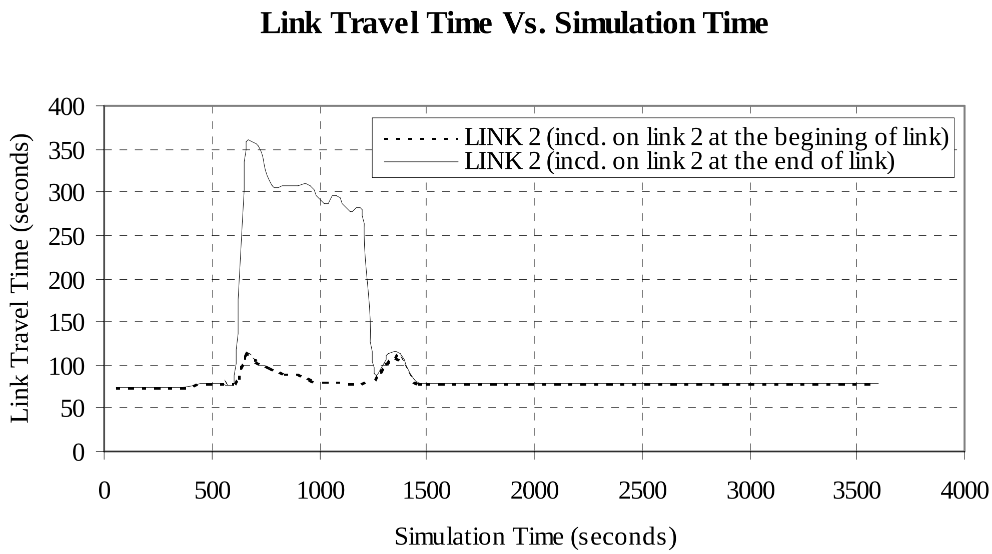


Figure 54. Comparison of travel times of link 2 for scenario 3

When the incident occurs at the end of link 2, the entire link is impacted by the incident, causing a very strong backward shockwave propagation to link 1 (since link 1 is upstream of link 2). This caused a sharp increase in the link density due to increased stalling of vehicles at the end of link 1, which are ready to leave link 1, but cannot due to the reduced intake of vehicles in link 2. Hence the link travel time on link 1 increases. This increase in travel time on link 1 starts to drop down soon after the incident on link 2 is cleared (at 1200 seconds), and then the travel time returns to normal and merges with the link travel time curve for no incident case. However, when the incident occurred at the beginning of link 2, only the beginning portion of link 2 is under the impact of the incident. Thus the backward shockwave to link 1 is not as strong as compared to what it is when the incident occurred at the end of link 2. Thus, the corresponding increase in the link density and hence link travel time of link 1 is also low when compared to the case when the incident occurred at the end of link 2.

When the incident occurs at the end of the link, all link 2 experience the effects of the incident. Thus, the density of link 2 increased significantly more than the case when the incident occurred at the beginning of the link because then only a small portion of link 2 is under the effect of the incident.

Link Traffic Density

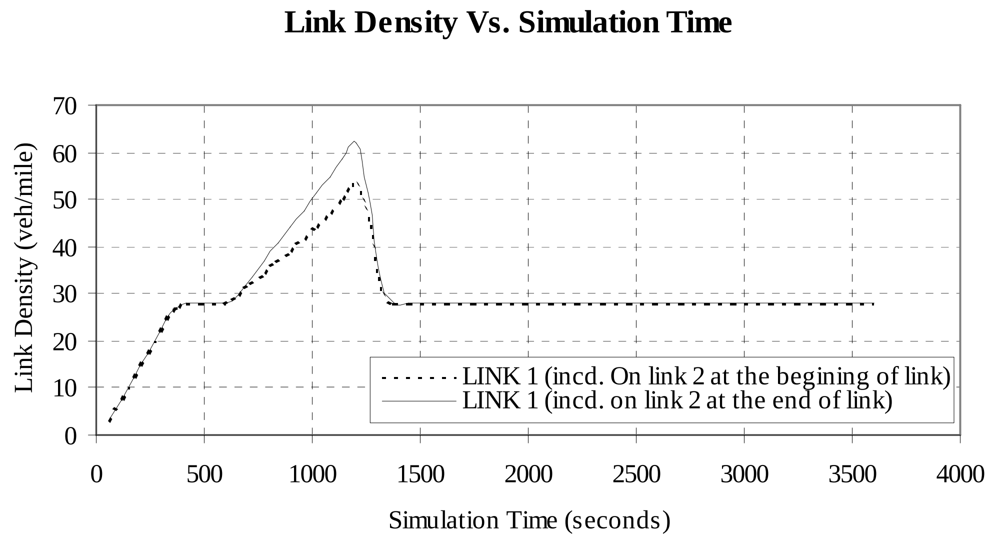


Figure 55. Comparison of vehicular link densities of link 1 for scenario 3

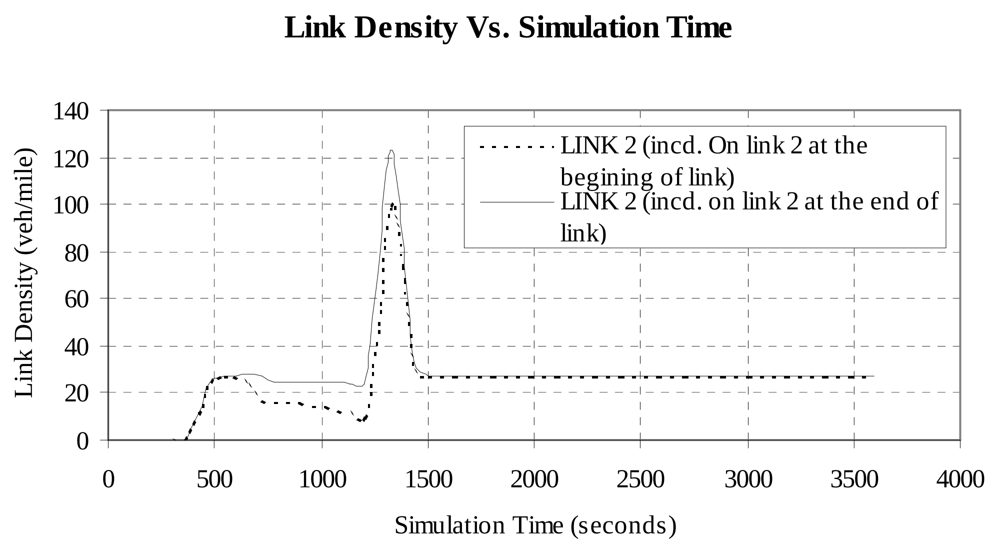


Figure 56. Comparison of vehicular link densities of link 2 for scenario 3

Effects of Incident Detection Technologies

Scenario 4

This scenario is designed to depict the effect of VMS. It compares the results of two runs of the simulation model. It involves four links, namely links 6, 12, 19 and 20. Both runs have an incident occurring on link 20. The first simulation run has no VMS installed at links 6 and 12 (upstream links of links 19 and 20), and hence there is no diversion of vehicles around the incident.

In the second run, there is a VMS installed of links 6 and 12, and hence there is diversion at the junction node, with vehicles being diverted to the non-incident link (link 19).

Table 44. Incident details for link 20

Incident Link number	Number of lanes blocked	Total number of lanes	Start time (seconds)	End time (seconds)
20	2.0	5	1200	3000

Table 45. Free flow travel times for link 19 and link 20 - Scenario 4

Link	Free flow travel time (seconds)
19	63.50
20	65.50

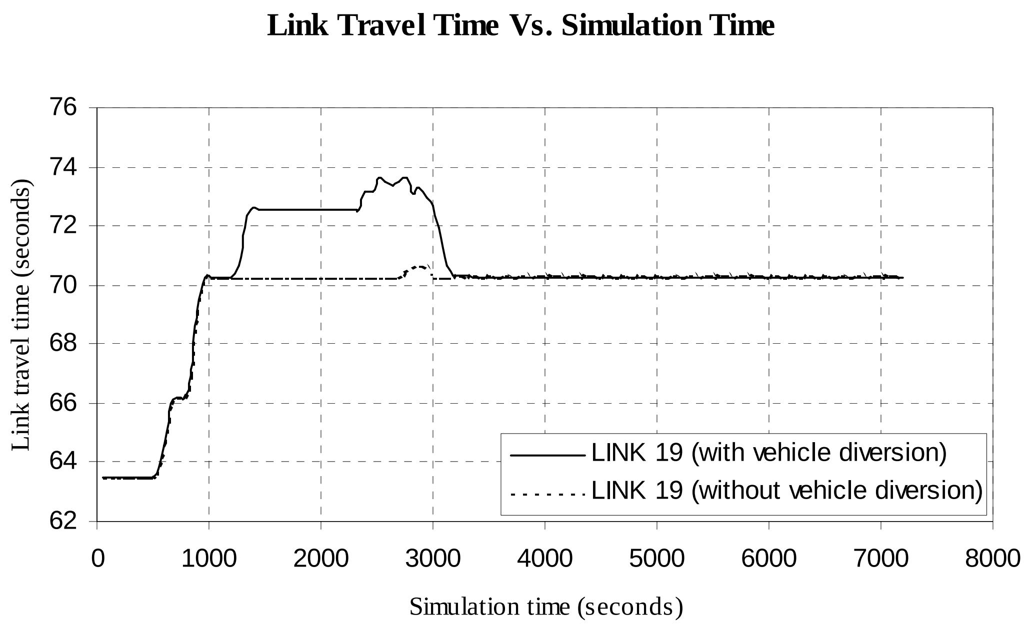


Figure 57. Comparison of travel times of link 19 for scenario 4

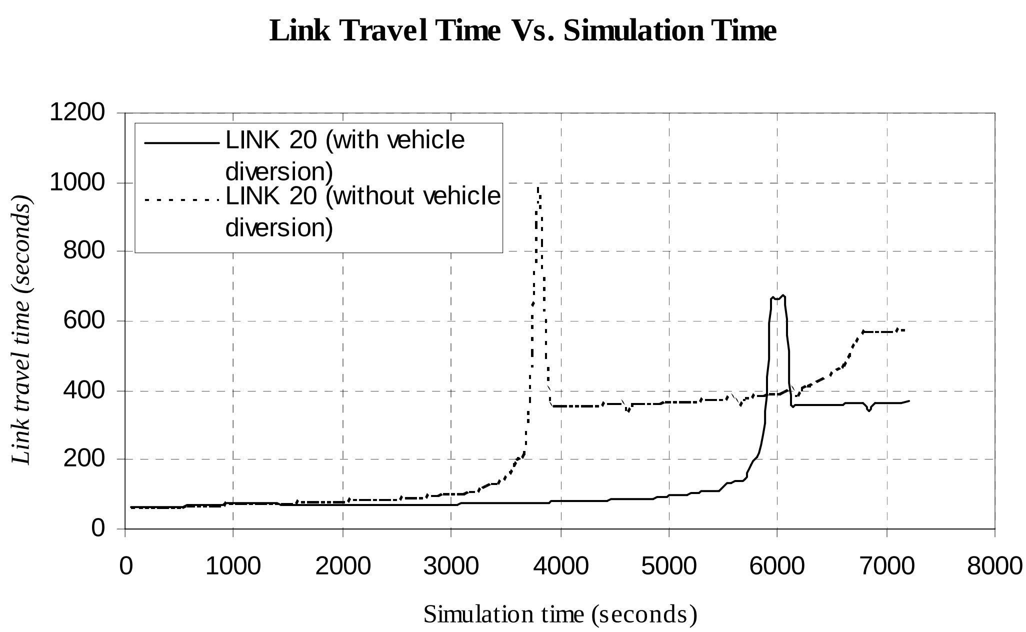


Figure 58. Comparison of travel times of link 20 for scenario 4

Table 46. Vehicular jam densities for link 19 and link 20 – Scenario 4

Link	Jam density (vehicles/mile)
19	720
20	720

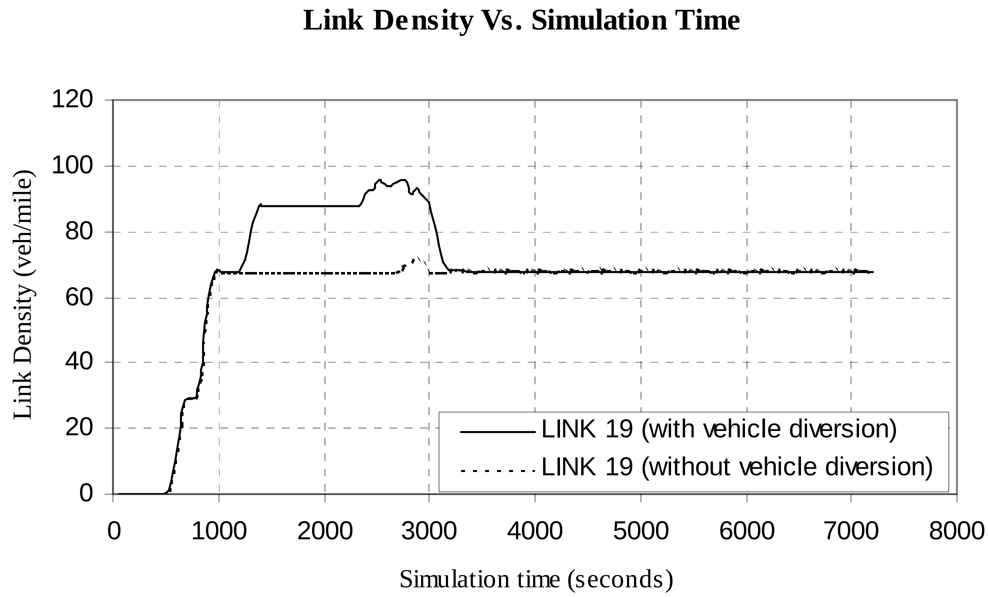


Figure 59. Comparison of vehicular link densities of link 19 for scenario 4

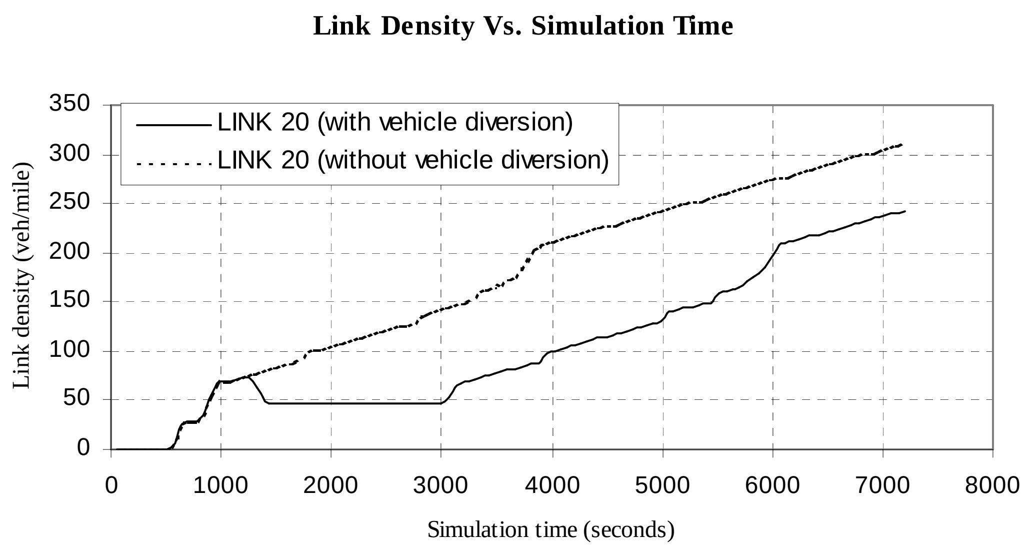


Figure 60. Comparison of vehicular link densities of link 20 for scenario 4

As illustrated in the above figures, when there is a VMS installed in the upstream links of the incident link (link 20), the vehicles present in the upstream links receive information about the incident on link 20, and hence some percentage of the vehicles are diverted to the non–incident link (link 19). This in turn resulted in a decrease in the link density and hence link travel time of link 20. A steep increase is observed in the travel time of link 20 once the incident is cleared. This is attributed to the fact that after incident clearance, the number of vehicles entering link 20 is restored back to normal. Thus, the link density and travel time of link 20 sharply increases for a short time but soon became approximately constant after a short time span.

As for link 19, an increase in the link density during incident duration is observed when there is a VMS installed in the upstream links because after the incident occurrence on link 20, many of the vehicles which are previously going into link 20 started diverting to link 19, thus increasing its link density and link travel time. However, soon after incident clearance, the link density and travel time of link 19 decreased and merged with the corresponding curve for the no diversion case because now the number of vehicles entering link 20 is restored back to normal. The increase in travel time of link 19 is not as significant as the decrease in the travel time of link 20, due to the fact that the jam density of link 20 is decreased significantly because of the incident but the jam density of link 19 remained the same, as there is no incident on link 19. Therefore, even though the link density of link 19 increased significantly after vehicle diversion, the travel time did not as the existing capacity of link 19 is being utilized.

Scenario 5

This scenario is designed to illustrate the effect of the percentage of cellular phone users among travelers on the incident detection time. The simulation model is run about ten times with incidents occurring at different links with different values for the percentage of cellular phone users and the impact on the incident detection time is observed.

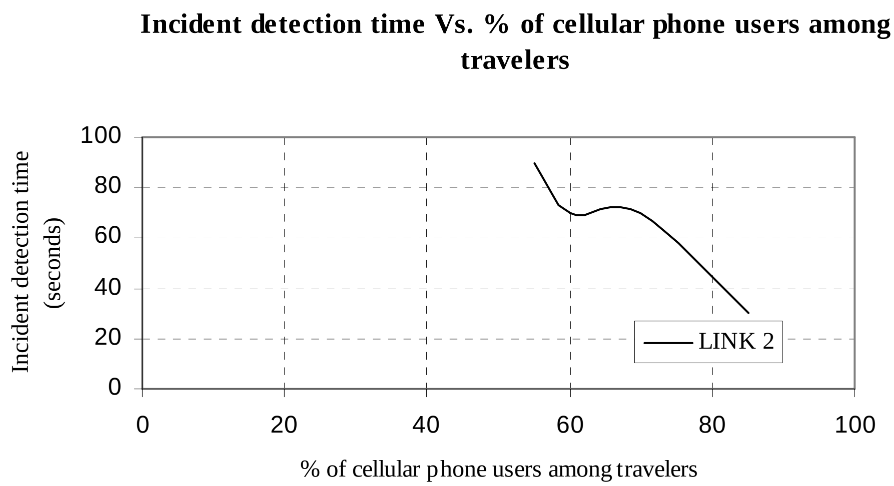


Figure 61. Impact of % of cellular phone users on incident detection time for link 2 for scenario 5

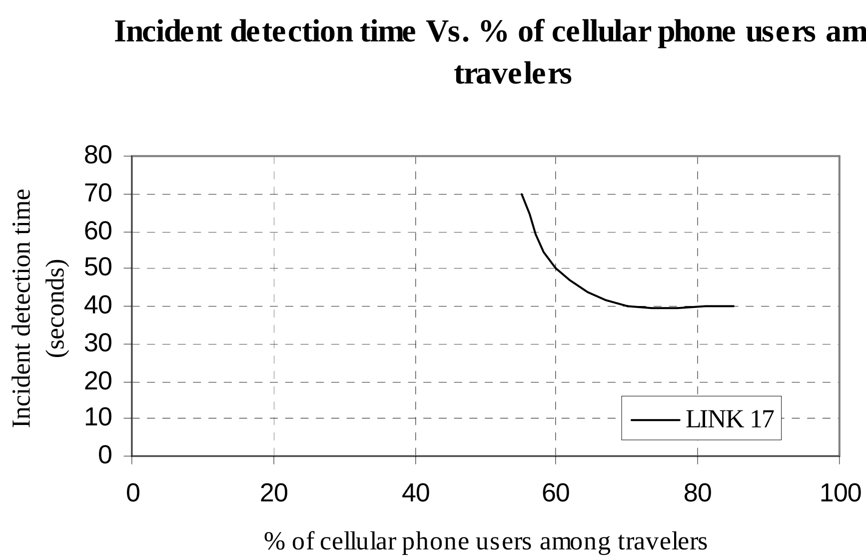


Figure 62. Impact of % of cellular phone users on incident detection time for link 17 for scenario 5

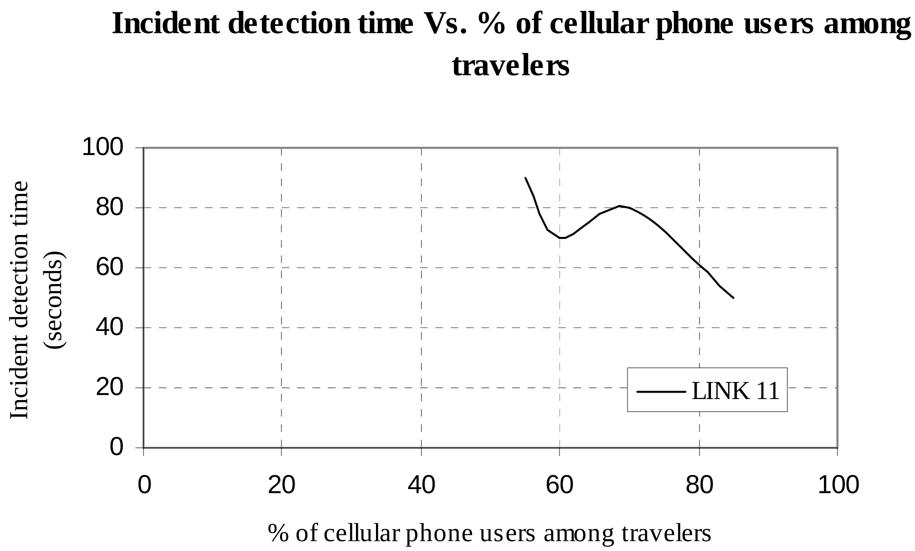


Figure 63. Impact of % of cellular phone users on incident detection time for link 11 for scenario 5

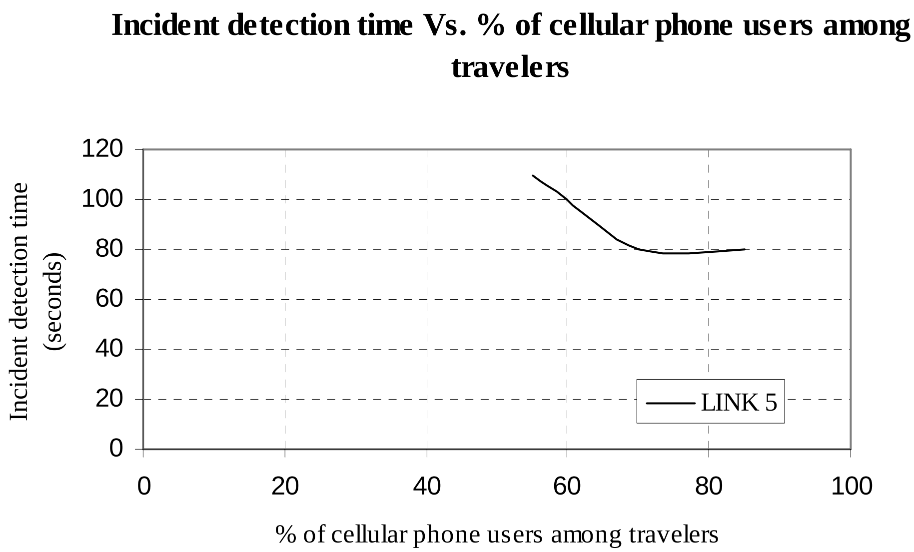


Figure 64. Impact of % of cellular phone users on incident detection time for link 5 for scenario 5

It is observed that in most cases, an increase in the percentage of cellular phone users among travelers resulted in a decrease in the incident detection time because more cellular phone users mean more cellular calls made to the TMC, thus decreasing the time taken to detect and verify an incident. However, in few cases it is seen that sometimes an increase in the percentage of cellular phone users did not bring about a decrease in the incident detection time. This is due to the randomness provided in the simulation program to account for the fact that sometimes even though the percentage of cellular phone users among travelers is increased, it does not decrease the incident detection time because not all travelers might choose to report an incident occurrence that they might come across to the TMC.

The results obtained are in complete accordance with some previous studies done to assess the efficacy of incident detection by cellular phone call-in programs. For example, Mussa et al. [(38)] has conducted a research study about cellular phone call-in programs by using the Federal Highway Administration's freeway simulation model, FRESIM. The results attained by the study demonstrated that continued growth of the proportion of drivers with cellular phones has a major influence on the detection performance of a cellular phone call-in program. An increase in the percentage of cellular phone owners brought about a decrease in the incident detection time as also illustrated by the results of this simulation model. Table 47, Table 47 and Table 49summarize the effect of varying the percentage of cellular phone owners among travelers and varying the threshold number of cellular phone calls on incident detection times for various traffic demands in the South Jersey network obtained from the simulation model.

Scenario 6

This scenario is designed to demonstrate the effect of the threshold number of cellular phone calls (number of cellular phone calls received by TMC before an incident is assumed to be verified) on the incident detection time. The simulation model is run about ten times with incidents occurring on different links with different values for the threshold number of cellular phone calls and its impact on the incident detection time is studied.

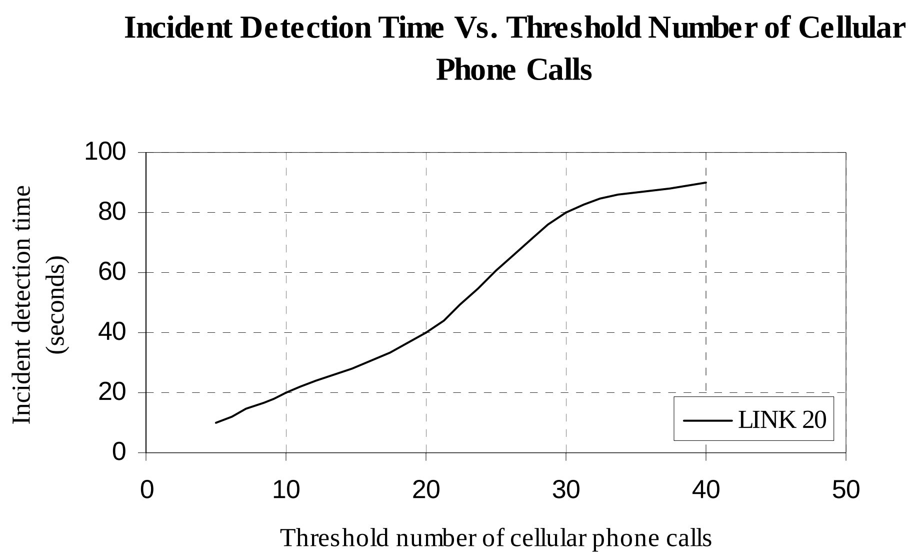


Figure 65. Impact of threshold number of cellular phone calls on incident detection time for link 20 for scenario 6

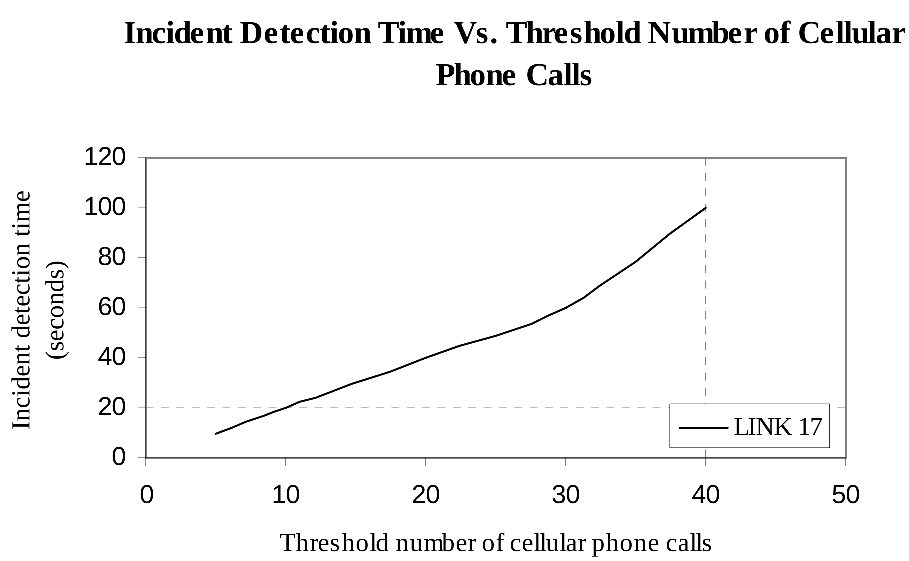


Figure 66. Impact of threshold number of cellular phone calls on incident detection time for link 17 for scenario 6

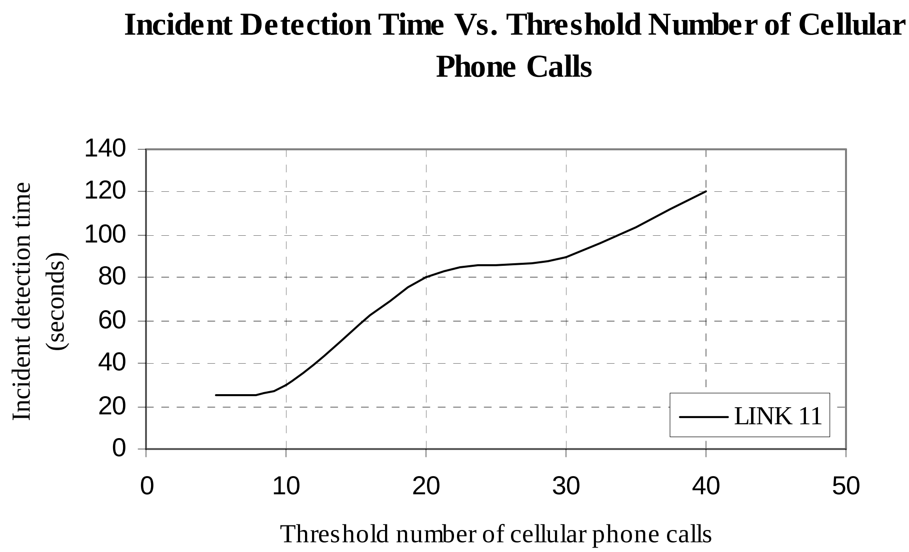


Figure 67. Impact of threshold number of cellular phone calls on incident detection time for link 11 for scenario 6

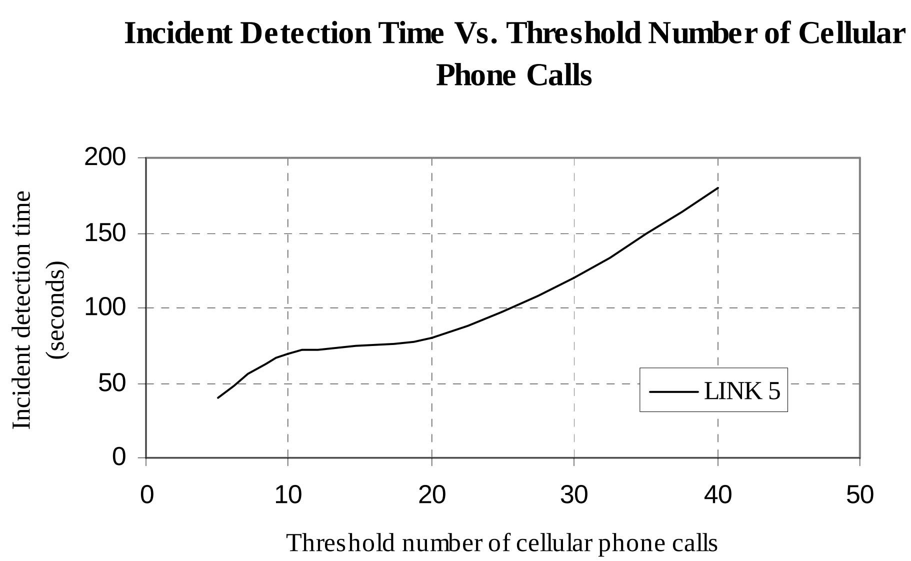


Figure 68. Impact of threshold number of cellular phone calls on incident detection time for link 5 for scenario 6

It can be observed from the above graphs that increasing the threshold number of cellular phone calls caused an increase in the incident detection time. This is a logical result because more number of threshold cellular calls means that TMC has to wait for a longer time before the incident is assumed as verified and a response unit is dispatched.

The results obtained agree with the research study conducted by Mussa et al. [(38)]. The results of their study demonstrated that there is a direct relationship between the probability of detection and the detection time; that is, the specification of a higher detection rate resulted in slower incident detection time.

In this simulation model, the probability of incident detection (detection rate) is modeled by the threshold number of cellular calls received by TMC, because the higher the number of threshold calls, the greater the probability of a correct incident detection and smaller the probability of a false alarm. Following is a tabulation of results obtained from the simulation model.

Table 47. Effect of percentage of cellular phone owners and threshold number of cellular phone calls on incident detection times for a demand of 1800 Veh/hr.

Percentage of cellular phone owners	Threshold number of cellular phone calls	Incident detection time (seconds)
10	20	230
	40	370
40	20	70
	40	100
70	20	40
	40	80
90	20	30
	40	50

Table 48. Effect of percentage of cellular phone owners and threshold number of cellular phone calls on incident detection times for a demand of 1100 Veh/hr.

Percentage of cellular phone owners	Threshold number of cellular phone calls	Incident detection time (seconds)
10	20	420
	40	830
40	20	120
	40	210
70	20	90
	40	100
90	20	40
	40	80

Table 49. Effect of percentage of cellular phone owners and threshold number of cellular phone calls on incident detection times for a demand of 550 Veh/hr.

Percentage of cellular phone owners	Threshold number of cellular phone calls	Incident detection time (seconds)
10	20	710
	40	960
40	20	200
	40	650
70	20	80
	40	410
90	20	70
	40	270

Table 50 illustrates the results obtained by Mussa et al. [38] for a test network. The observed impacts of the percentage of cellular phone owners and probability of detection (similar to threshold number of cellular phone calls) on incident detection time found by Mussa et al. [38] is similar to that achieved by the simulation model developed in this study. The difference in numbers is due to the different traffic demands, different networks, and the different models applied to calculate the detection times in both the studies.

Table 50. Detection performance of a simulated cellular detection system (38)

Traffic demand (Veh/hr./lane)	Percentage of cellular phone owners	Probability of detection	Incident detection time (seconds)
700	10	90	198
		30	18
1550	10	60	36
		90	90
	90	90	12
2000	10	90	66

Effects of Incident Management and Resource Allocation Strategies

Consider the daily operations of the incident management system implemented for the South Jersey highway network depicted in Figure 69. There are 7 main highways in this area. For analytical purposes, these highways are divided into short sections using hypothetical nodes. A patrolling route can consist of any sections as long as they form a continuous route. The patrol service vehicles travel along the route back and forth until they encounter an incident. After the incident is cleared, the patrol vehicles resume their patrolling duties along the route. In this study, a single depot and a single patrolling route case is considered. There can be zero or multiple service vehicles traveling along the patrol route, but at least one service vehicle should be assigned to the depot, since it is assumed only the service vehicle in the depot can effectively respond to the incident that occurs anywhere on the network. Consider an existing incident management system (IMS), where the location of the depot and the patrol route are both fixed. To improve the efficiency of such a system, the following factors that remain adjustable are focused: the number of service vehicles assigned to the depot, FSP, and the dispatching policy. Table 51 summarizes these factors as candidate independent variables for the response surface to be constructed. The values in the parenthesis in the last column specify the range of these variables.

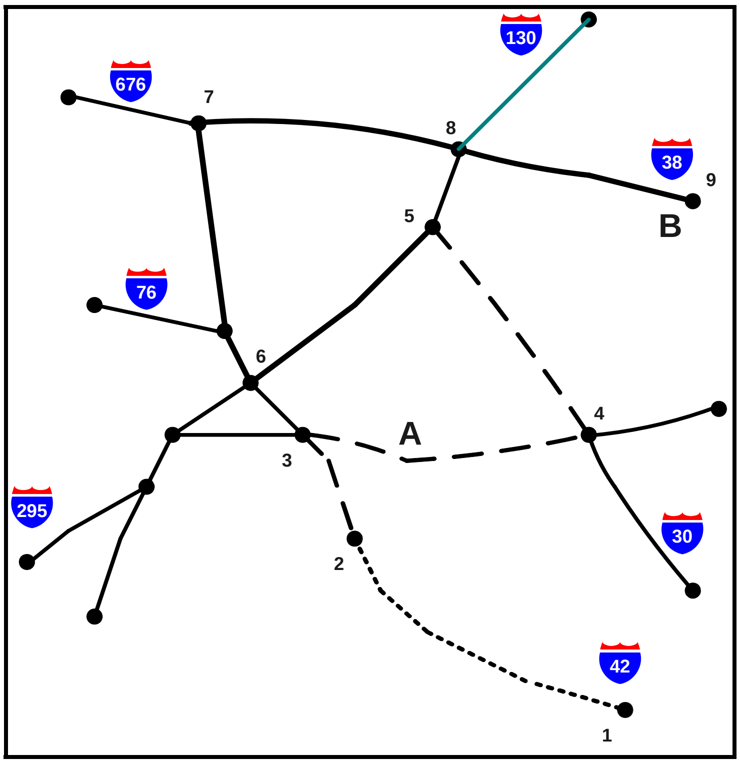


Figure 69. South Jersey roadway network

Table 51. Definitions of candidate control variables

Variables	Meaning	Type
x	The number of service vehicles in the depot.	Integer (1~9).
p	Dispatching policy for the service vehicles in the depot.	Dummy (0-FCFS or 1-NN).
r	The number of service vehicles in the FSP.	Integer (0~4).

The incident duration is the time elapsed since the incident occurrence until its clearance. As shown in Figure 70, the overall duration of an incident, from beginning to end, can be divided into several smaller periods: detection time (t_n), dispatch time (t_d), travel time (t_t) and clearance time (t_c). Compared to the depot option, FSP could save valuable detection, dispatching and travel time by clearing incidents along its patrol route.

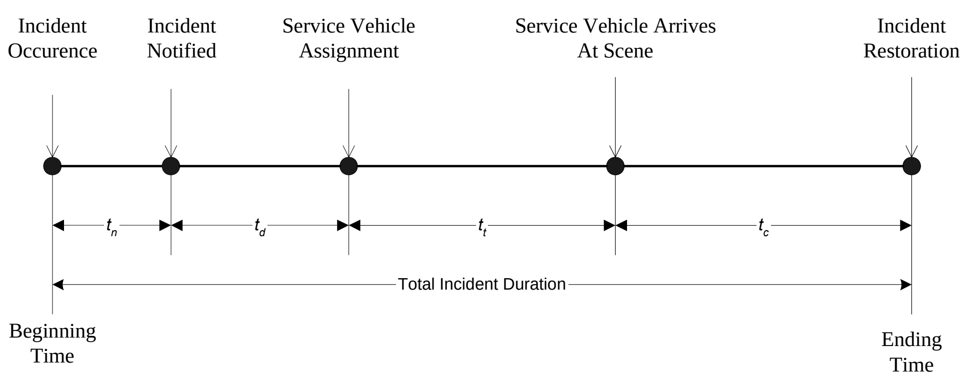


Figure 70. Simplified time line of incident duration

One of the critical functions of an IMS is to clear the incident as fast as possible. Average incident clearance duration (*AICD*) is chosen as the response variable, which is defined as the sum of the clearance durations of all incidents in a simulation run divided by the total number of incidents that have occurred in that simulation run. The reasons for doing so are twofold. First, the incident duration is an important measure for evaluating the effectiveness of an IMS. The shorter the incident duration, the smaller the adverse impact that this incident will cause. Second, incident duration is easier to measure compared to other measures, such as pollution, gas consumption, and traffic delay. The objective of this case study is to evaluate these two distinct incident management strategies in terms of reducing *AICD*, using the simulation models combined with response surface methodology.

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response (82). Most applications of RSM have three phases, which are summarized in Figure 71. In this case, since all the candidate independent variables considered are discrete variables varying in small ranges, it is possible to use a surface to fit the whole variable space. Once this surface is obtained, determining the optimal point follows immediately.

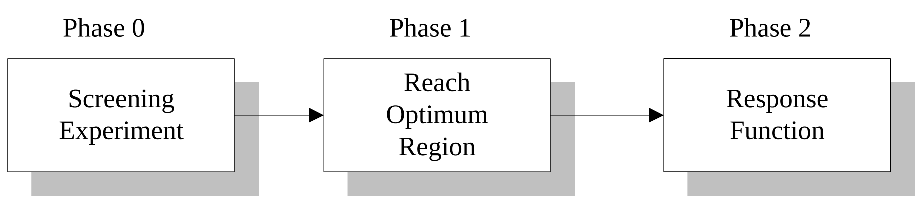
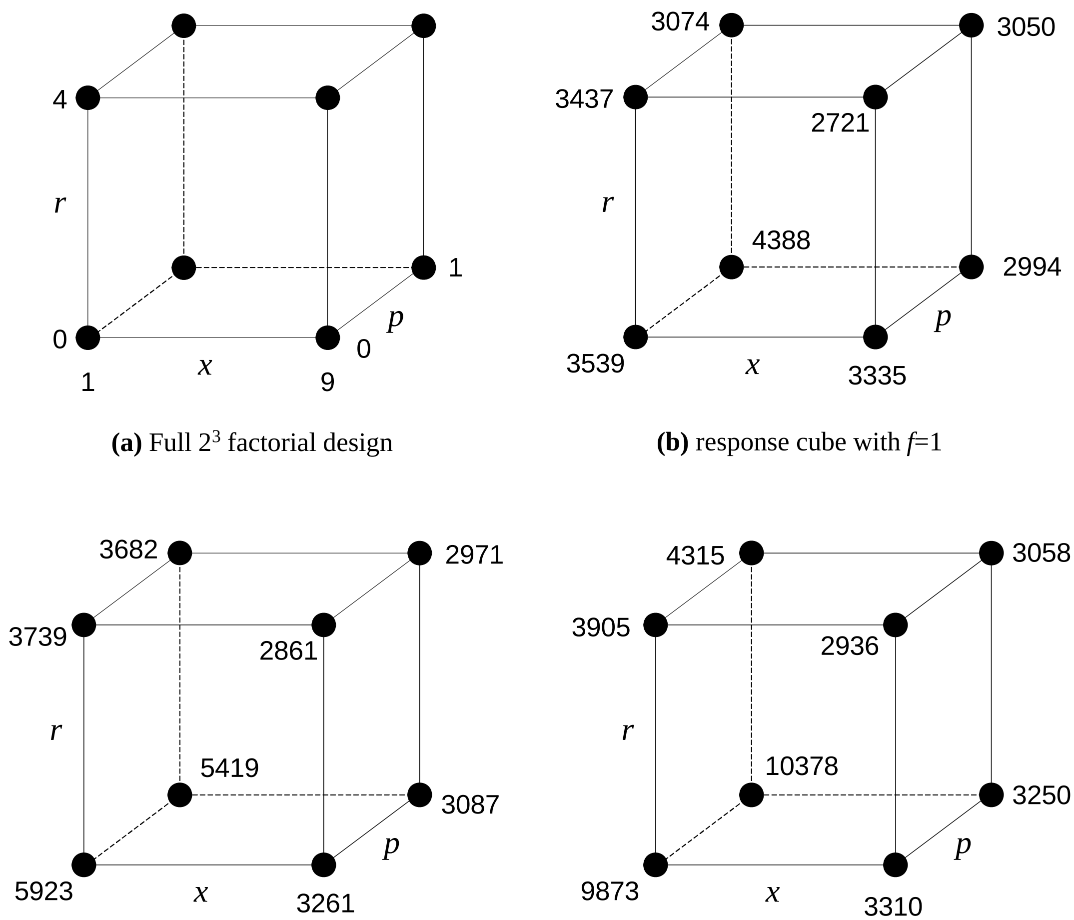


Figure 71. Three Phases of RSM

Let *y* denote the response variable, the *AICD,* in seconds. Let *f* denote the average number of incidents that might occur over the roadway network during a given time period. It is assumed that there can be up to nine service vehicles in the depot and four service vehicles as part of the FSP due to the budget constraints. Note that the number of vehicles in the patrolling service could be zero, which means no patrolling service is offered in this IMS. Simulation runs are performed for incident frequency levels varying from one incident to nine incidents during the simulation period under the scenarios that range between the light traffic conditions to the heavy traffic conditions. Note that to observe the effects of different resource allocation strategies under various traffic conditions, incident occurrence frequency is taken as a controllable variable. Thus, in this case study, the incidents are generated according to a Poisson process instead of using the incident database. The simulation results for each scenario provide data points used to develop the response surface.

Screening Experiments

The goal of screening experiments is to shorten the list of candidate variables to a relatively small number or to make sure that all selected variables have statistically significant effects on the response. The simplest of the screening experiments are the two-level factorial designs. To perform a general two-level factorial design, two extreme levels are chosen for each of the three candidate variables and then complete experiments with all possible combinations. Since there are three possible independent variables in this experiment, the screening design will be a full 2^3 factorial design requiring eight runs. The upper and lower levels for these factors are shown in Figure 72. Each vertex on the cube represents settings for the three control variables, which is used at three traffic conditions. Figure 72 show the response cube based on the simulation runs for each setting under different frequency of incident occurrence. The value beside each vertex in the response cube is the *AICD* resulted from the settings described in the vertex.



(a) Full 2^3 factorial design **(b)** response cube with *f*=1

(c) response cube with *f*=3 **(d)** response cube with *f*=6

Figure 72. Full factorial design and resulting response cubes

The response cubes show that increasing the number of service vehicles in the depot reduces the average duration time significantly for all three traffic conditions. Since the response values, with nine service vehicles allocated to the depot, are reduced to same level (around 3000 sec) for all three incident frequencies, it is useful to know the optimal number of service vehicles in terms of maximizing the return on investment ratio. The patrolling service also reduces the incident duration, but its effect is not as significant as increasing the number of service vehicles. Comparing the improvement due to the patrolling service at *x*=1 and *x*=9, it is found that when there are not enough service vehicles available, the improvement due to patrolling service is more significant. The effect of dispatching policy is mixed. When there are a large number of service vehicles (either in the depot or patrolling along the patrol route), using different dispatching policies does not make a significant difference. If the available service vehicles are scarce compared to the high incident frequencies, then NN outperforms FCFS. For instance, at f=3 and x=1, the average duration time with NN is almost 10 percent less than FCFS. On the other hand, if the number of service vehicles can satisfy the resource demands by the incidents, then FCFS gives better performance. This is illustrated by the scenario with f=1 and x = 1.

Since all three candidate independent variables have significant effects on the *AICD* at least for some specific settings, all are kept in the final independent variable list. Figure 72 illustrates the effect of each factor. In the following sections, statistical models are developed to discover the relationship between the average duration and these variables in a more precise way.

Response Models Focusing on Depots

This section is devoted to examining the effects of depots, including impact of the number of service vehicles, dispatching policies, and the location of the depot. Since the *AICD* decreases quickly as the number of service vehicles in the depot, x, increases, it is useful to know the response of x at various traffic conditions. In the following tests, the dispatching policy is fixed as FCFS, excluding the patrolling service, while the number of service vehicles and the frequency of incidents vary from an average of one incident during the simulation period to an average of nine incidents during the same period. The total number of scenarios is 81. Fifty replications of each of the 81 scenarios are run, providing 4,050 independent data points that are used to develop the response surface. The collected data demonstrate a negative exponential relationship between the *AICD* and the number of service vehicles. The *AICD* decreases very fast in the beginning when the number of service vehicles is increasing. When the number of service vehicles continues to increase, the rate of decrease of *AICD* slows down, and it decreases very slightly after the number of service vehicles reaches five. From this observation, it is assumed that the *AICD* follows an exponential model which has the following form: $y = ce^{g(x,f)} + d$, where $g(x, f) = k_x x + k_f f$, and c, d, k_x and k_f are the parameters need to be determined. Fitting a nonlinear regression model to data is slightly more involved than fitting a linear model. SAS™ (version 8.2) software is used to fit this model. Newton fitting algorithm is applied. After twelve iterations, the convergence criterion is met, and the estimated parameters and the goodness of fitness are shown in Table 52 and Table 53.

Table 52. Regression analysis results

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
c	3370.5	298.3	2776.6	3964.4
k_x	-0.9482	0.0455	-1.0388	-0.8575
k_f	0.2490	0.0100	0.2291	0.2690
d	3246.2	53.9343	3138.8	3353.6

Table 53. Goodness of fitness

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Regression	4	1.8288E9	4.572E8	910.70	<.0001
Residual	77	10312989	133935		
Uncorrected Total	81	1.8391E9			
Corrected Total	80	3.7624E8			

The quality of fit of linear regression models are expressed in terms of the coefficient of determination, also known as R^2. In nonlinear regression, such a measure is unfortunately, not readily defined. A measure that relatively closely correspond to R^2 in the nonlinear case is R^2_{pseudo}, defined as

$$R^2_{pseudo} = 1 - \frac{SS_{Residual}}{SS_{Total\ corrected}}. \tag{12}$$

Using the values presented in Table 53, equation (1) yields R^2_{pseudo} = 0.9726. In summary, the model depicts the relationship between the *AICD* and the number of service vehicles in the depot and the incident frequency as

$$y = 3370.5e^{-.9482x + 0.2490f} + 3246.2 . \quad (13)$$

Figure 73 presents the three-dimensional graph of the *AICD*, with the number of service vehicles in the depot and the incident frequency as the independent variables. In Figure 73 it can be seen that the *AICD* decreases quickly as the number of service vehicles increases. At high incident frequency levels, the *AICD* decreases slower compared to the case at the low incident frequency levels. Increasing the number of service vehicles beyond four does not help much to reduce the *AICD*.

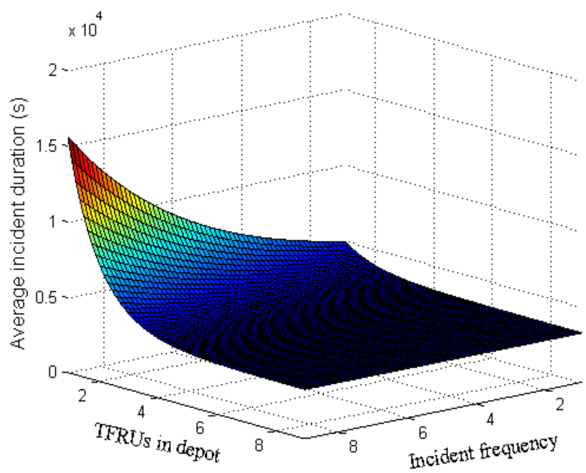


Figure 73. Response surface with incident frequency and service vehicles

Another interesting issue is the impact of dispatching policy on the response variable. Changing the dispatching policy to *NN* and repeating the above experiments, another non-linear model is obtained as follows:

$$y = 3956.8e^{-1.0989x + 0.2567f} + 3280.9 . \quad (14)$$

To compare these two dispatching policies, the simulation results of FCFS and NN are plotted together in Figure 74. It shows that two dispatching policies demonstrate no remarkable differences when *x* is increased beyond four. This means the dispatching policy is not important when the available service vehicles are greater than the number of service vehicles needed by incidents. However, the decision maker should be careful when there are not many available service vehicles. As shown in Figure 74, NN outperforms FCFS for most cases when the number of available service vehicles is less than five.

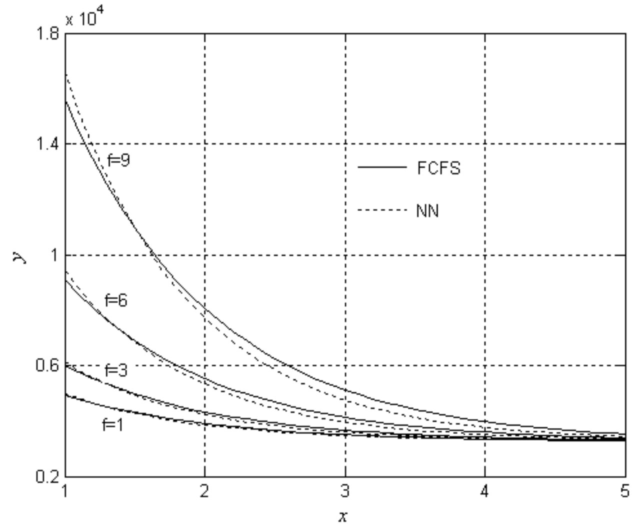


Figure 74. FCFS vs. NN

Since relocating the depot is expensive and unrealistic in most situations, the location of the depot is not selected as an independent variable. In the following section, the importance of the location of the depot is shown by comparing two possible locations of the depot: location A is at the center area of the roadway network, while location B is at the edge, as shown in Figure 69. For each location, 4 levels of incident frequency are tested. The dispatching policy was set to FCFS while increasing the number of service vehicles. The obtained model for location B is given as follows:

$$y = 4843.2e^{-.9754x+0.2548f} + 3654.5\,. \tag{15}$$

The effect of these two depot locations is compared in Figure 75. It can be seen that the *AICD* increases significantly if we move the depot from A to B, especially when the incident frequencies are high. This can be explained as follows. The average travel time from the center of the roadway network to the incident sites, which is distributed randomly over the network, is smaller than the average travel time from the edge of the network to the incident sites.

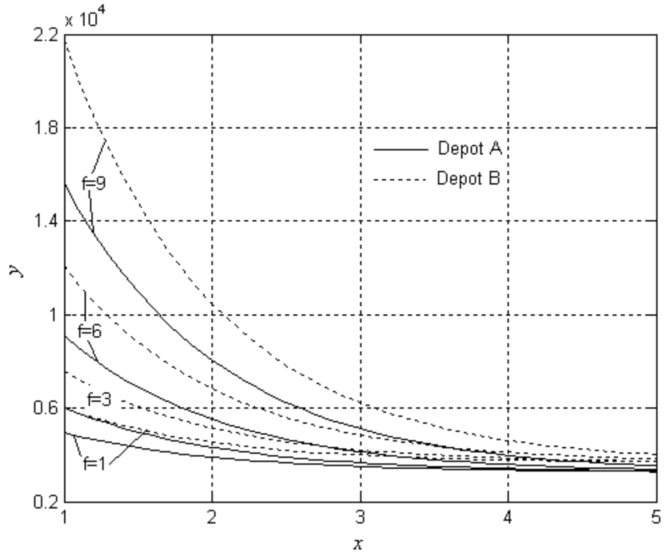


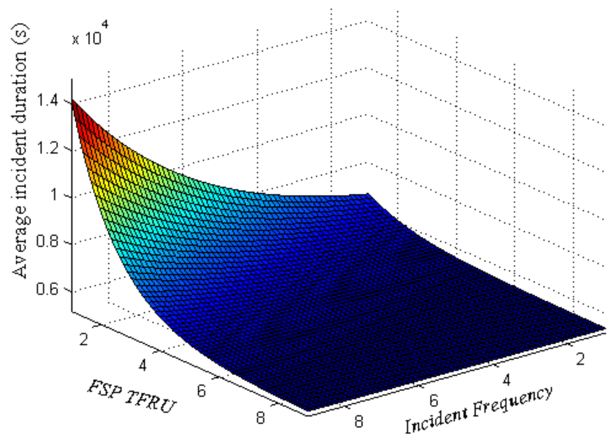
Figure 75. Effect of the location of the depot

Models Focusing on Freeway Service Patrol

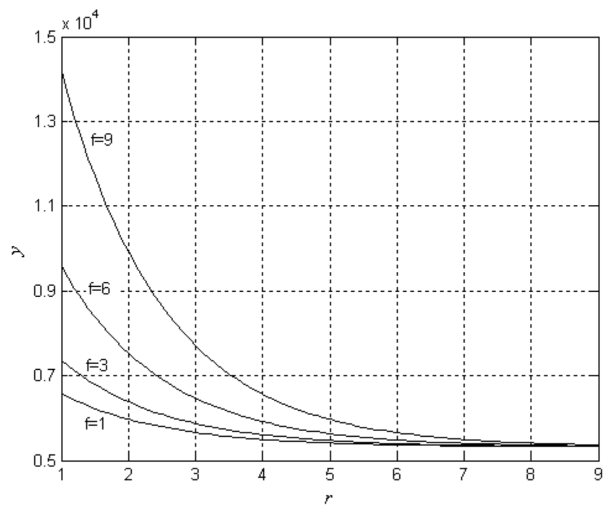
Currently, a typical patrol route in South Jersey covers all of I-76, I-676 and NJ42. To show the effect of the FSP, the number of service vehicles on this patrolling route is changed, while keeping one service vehicle at the depot ($x = 1$) and using FCFS dispatching policy only. Similarly, non-linear regression analysis is used and another model is obtained to show the impact of the number of service vehicles in the FSP:

$$y = 1894.7e^{-.6537r+0.2438f} + 5320.0\,. \tag{16}$$

The response surface of service vehicles in the FSP and the incident frequency is depicted in Figure 76 (a). The 2-D curves for specific *f* values are shown in Figure 76(b). The *AICD* decreases significantly when the number of service vehicles used by FSP increases, especially in the cases with high incident frequency level. This shows the importance of FSP for the IMS' performance.



(a) Response surface



(b) Curves for specific *f* values.

Figure 76. Response surface of FSP and incident frequency with x = 1

In the single patrol route case, the effect of the length of the patrolling route is also studied. Three patrol routes illustrated in Figure 69 are also compared to the single realistic patrol route. The short patrol route is depicted by the dotted line, from node 1 to node 2. The patrol route of middle length extends the patrol route to node 5, which is the combination of the dotted line and dashed line. The longest patrol route extends the middle length route along nodes 5, 6, 7, 8, to 9. The performance of different patrol routes is evaluated under the same traffic condition, where f = 6, while keeping one available service vehicle in the depot.

The number of service vehicles assigned to these patrol routes is increased from one to nine, and the curves of *AICD* for each route are shown in Figure 77. It can be seen from Figure 77 that, for the scenario considered in this study, the longer patrol route results in shorter *AICD*. Additionally, the current typical patrol route is a reasonable choice, and it is outperformed only by the longest patrol route chosen for the simulation analyses.

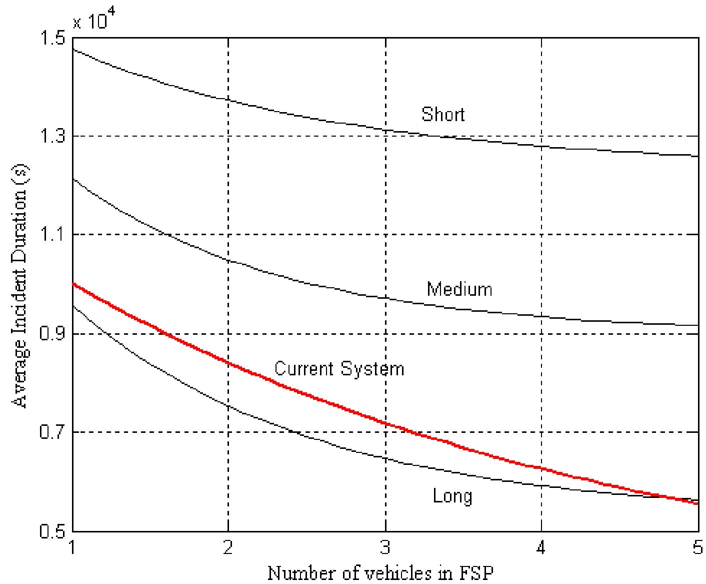


Figure 77. The effect of patrol route length

Combination of FSP and Depot

In this section, the combined impact of the number of service vehicles in the depot and the number of service vehicles on the current patrol route on the *AICD* are demonstrated. The following model is used to fit the data:

$$y = ce^{g(x,r,f)} + d \tag{17}$$

where $g(x,r,f) = k_x x + k_r r + k_f f + k_{xr} xr$ and k_{xr} is the parameter of the interaction of service vehicles in the depot and FSP. Similar to previous sections, Newton fitting algorithm is used to estimate the parameters of the model. After 17 iterations of the Newton fitting algorithm, the convergence criterion is met. The values of estimated parameters and the goodness of fitness are summarized in Table 54 and Table 55.

Table 54. Fitting results

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
c	4725.1	289.3	4156.7	5293.5
k_x	-0.8543	0.0331	-0.9192	-0.7894
k_r	-0.1681	0.0301	-0.2273	-0.1089
k_f	0.2462	0.00606	0.2342	0.2581
k_{xr}	-0.1071	0.0262	-0.1587	-0.0556
d	3329.3	29.7064	3270.9	3387.6

Table 55. Goodness of fit

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Regression	6	1.034E10	1.7232E9	1493.53	<.0001
Residual	480	1.275E8	265631		
Uncorrected Total	486	1.047E10			
Corrected Total	485	2.1111E9			

Using the values in Table 55, equation (9) yields R^2_{pseudo} = 0.94, which demonstrates that the model fits the data very well. Thus, the resulting model depicting the combined effect of FSP and the depot is given as follows:

$$y = 4725.1e^{(-0.8543x - 0.1681r + 0.2462f - 0.1071xr)} + 3329.3\,. \quad (18)$$

If the number of service vehicles in the depot and FSP are allowed to increase freely, Figure 78 shows the response surface when *f* = 3. Increasing the number of service vehicles in the depot or increasing the number of service vehicles in the FSP reduces the *AICD* significantly.

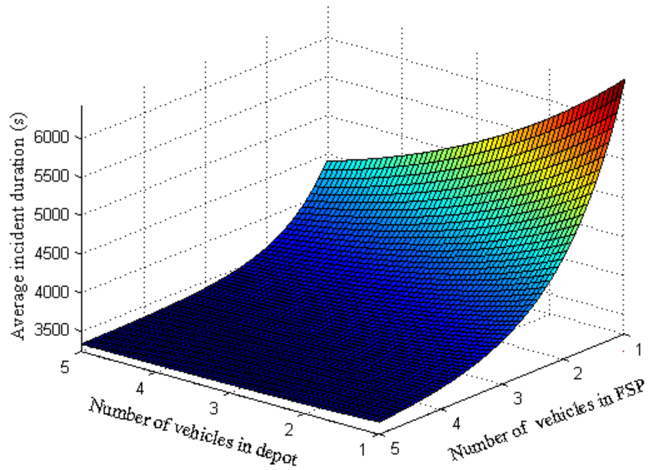


Figure 78. Response Surface of FSP and service vehicle with f=3

BENEFIT-COST ANALYSIS OF VARIOUS INCIDENT MANAGEMENT STRATEGIES USING THE SIMULATION FRAMEWORK

In this chapter, the cost-benefit analyses of the following incident management technologies are performed based on the simulation results.

- Incident Detection Technologies
    - Closed Circuit Television (CCTV)
    - Loop detector
- Traffic Management
    - Variable Message Sign (VMS)
- Incident Response
    - Freeway Service Patrol (FSP)

The following sections describe the cost benefit analysis and present the benefit cost ratios obtained for the above incident management technologies. The test network illustrated in Figure 79 is used in the simulation analyses.

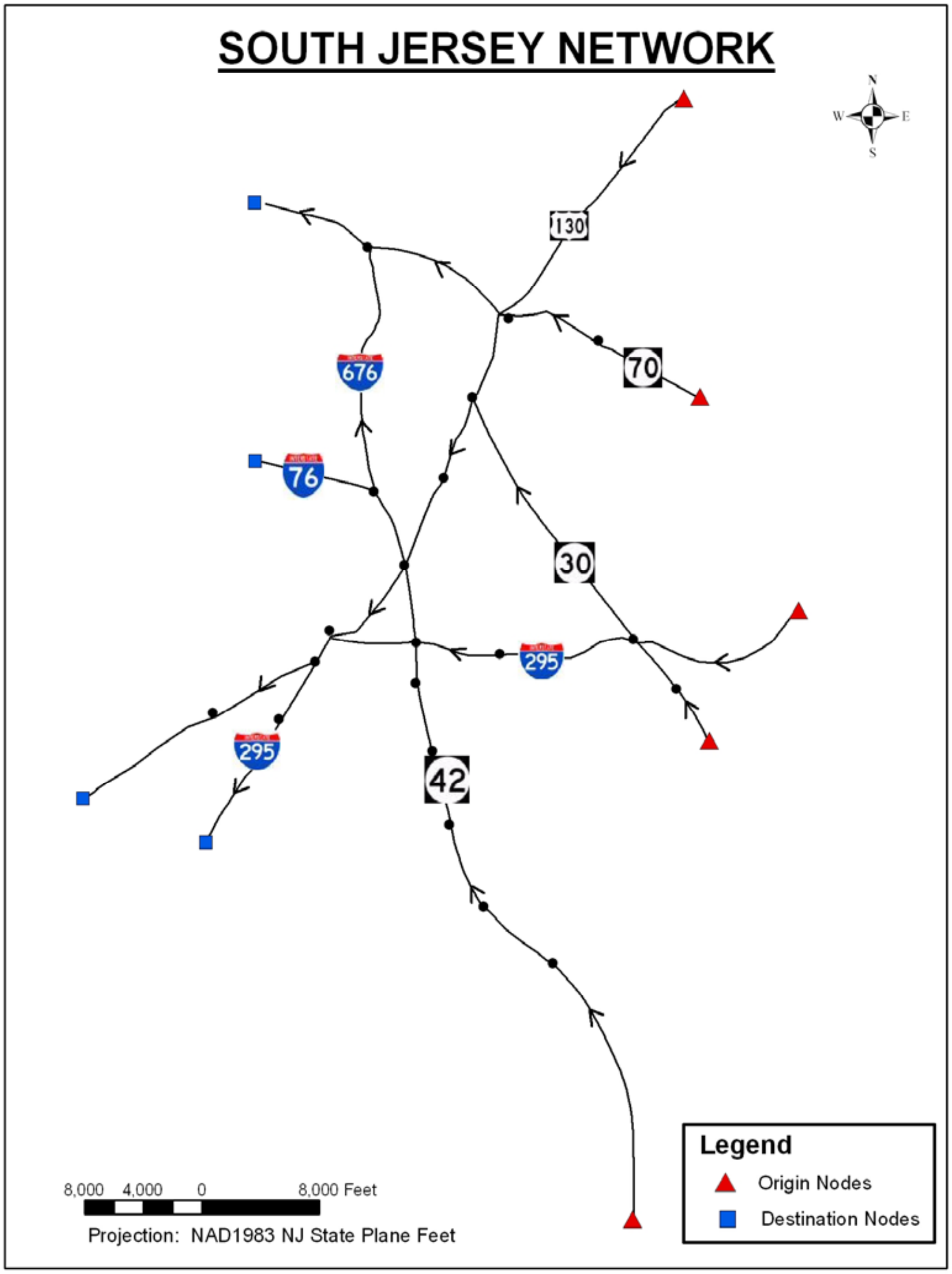


Figure 79. South Jersey study network

Benefit/Cost Analysis of Incident Detection Technologies

Routes 295,130 and 76 in the South Jersey test network are used for the analyses in this section. The technologies considered for incident detection are loop detectors and CCTVs. The methodology implemented to estimate the benefits and costs of these technologies was explained in previous chapters. The equations used in the benefit-cost analysis are introduced briefly as follows. Present value of cost can be computed as,

$$PVC_k = \frac{TC_k}{(1+i)^k}, \quad (19)$$

where PVC_k is present value of cost in year *k*, TC_k is total cost in year *k*, and *i* is discount rate.

The benefit-cost ratio can be calculated as:

$$B/CRatio = \frac{\sum_{k=1}^{K} PVB_k}{\sum_{k=1}^{K} PVC_k}, \quad (20)$$

where PVB_k is present value of benefit in year *k* and PVC_k is present value of cost in year *k*.

The costs of the various technologies considered are summarized in the following Table 56.

Table 56. Costs of incident detection technologies for freeways [22]

Technology	Unit Capital Cost ($K)		Os & Mt Cost ($K)	
	Low	High	Low	High
Loop Detectors on Corridor (Double set, 4 units)	3	8	0.5	0.8
CCTV Video Camera	7.5	17	1.5	2.4
CCTV Video Camera Tower		12		

According to ITS Unit Cost Database [22], the average annual capital cost of deploying loop detectors (double set, 4 units) is \$5,500. The average annual operations and maintenance cost is \$650 [22] with a lifetime of five years. Four units of loop detector are required per mile per lane. The average annual capital cost of deploying CCTVs on corridors is \$12,250. The average annual capital cost of constructing CCTVs tower on a corridor is \$12,000. The average annual operations and maintenance cost of a CCTV camera is \$1950. The lifetime of a CCTV camera is around 10 years, while the lifetime of a CCTV camera tower is approximately 20 years. One unit of CCTV is needed per mile.

The benefit cost analysis of loop detectors and CCTVs for the South Jersey network is performed using the simulation model based on the methodology described in previous chapter. The following is a summary of the results of the analysis obtained for the various routes. Note that, if not stated otherwise, the analysis is based on a 20-year period with a four percent discount rate, i.e., k = 20, and i = 4%. According to Wilbur Smith Associates [40], it is also assumed that the monetary value of time (including the user cost savings related to lost travel time or delay savings per year and savings in lost fuel cost per year) saved in terms of veh-hrs is \$12.85/veh-hr.

<u>Route 76</u>

The following sections present the benefit cost analysis performed for Route 76:

Benefits of Incident Detection Using Loop Detectors

- Total vehicle-hours saved (in case of incident occurrence) in one year due to loop detectors on Route 76 is 11,474 veh-hrs.
- Total average annual benefits rendered due to loop detectors on Route 76 can be calculated as

$$PVB_k = \text{(veh-hrs saved annually)} \times \text{(monetary value of time)} = \$147{,}525.$$

Using the above values in the benefit estimation formulae yields the total average benefits of deploying loop detectors on Route 76 for 20 years: ($\sum_{k=1}^{20} PVB_k$) = $2,084,535.

Cost of Loop Detectors

There are sixty loop detectors deployed along the route. Using the cost estimation equation, the total cost of deploying loop detectors on this route is obtained as, ($\sum_{k=1}^{20} PVC_k$) = $389,623.

Benefit/Cost Ratio of Incident Detection Using Loop Detectors

The benefit-cost ratio for deploying loop detectors for incident detection on Route 76 over a period of 20 years is calculated to be 5.35.

A sensitivity analysis is also performed on the benefit cost computations to evaluate the effect of the different assumed parameters like the discount rate and monetary value of time on the benefit cost ratio.

First, the effect of varying the discount rate on the benefit cost ratio is demonstrated.

If the discount rate is equal to 5%, then the total average benefits of deploying loop detectors on Route 76 for 20 years is calculated as $1,929,633. The total average cost of deploying loop detectors on Route 76 for 20 years is calculated as $364,965. Consequently, the benefit-cost ratio for deploying loop detectors on Route 76 for a period of 20 years would be 5.28.

If discount rate is equal to 6%, then the total average benefits of deploying loop detectors on Route 76 for 20 years is $1,790,959. The total average cost of deploying loop detectors on Route 76 for 20 years is calculated as $342,765.

Thus the benefit-cost ratio for deploying loop detectors on Route 76 for a period of 20 years is 5.22.

Second, the effect of varying the monetary value of time on the benefit cost ratio is considered.

If the monetary value of time is equal to $11, then total average benefits of deploying loop detectors on Route 76 for 20 years is $1,783,436. The total average cost of deploying loop detectors on Route 76 for 20 years is $389,623. Accordingly, the benefit-cost ratio for deploying loop detectors on Route 76 for a period of 20 years is 4.58.

If monetary value of time is equal to $14, then the total average benefits of deploying loop detectors on Route 76 for 20 years is $2,269,828. The total average cost of deploying loop detectors on Route 76 for 20 years $389,623. Accordingly, the benefit-cost ratio for deploying loop detectors on Route 76 for a period of 20 years is 5.82.

The results of this sensitive analysis are summarized in Table 57.

Table 57. Sensitivity analysis for B/C ratio of CCTV

	Discount rate		Monetary value of time	
	5%	6%	$11/veh-hr	$14/veh-hr
Benefit	$1,929,633	$1,790,959	$1,783,436	$2,269,828
Cost	$364,965	$342,765	$389,623	$389,623
Benefit-cost ratio	5.28	5.22	4.58	5.82

Benefits of CCTV for Incident Detection

- Total vehicle-hours saved (in case of incident occurrence) in one year due to CCTVs on Route 76 is 13,457 veh-hrs.
- Total average annual benefits rendered due to CCTVs on Route 76 can be calculated as:

PVB_k =(veh-hrs saved annually) × (monetary value of time) = $174,181.

Using the above values in the benefit estimation formulae yields the total benefit of deploying CCTVs in twenty years as $2,461,185.

Costs of CCTV

Three units of CCTV are needed on Route 76. Using the cost estimation equation, the total average cost of deploying CCTVs on Route 76 for 20 years is obtained as, ($\sum_{k=1}^{20} PVC_k$) = $180,216.

Benefit/Cost Ratio of Incident Detection using CCTV

The Benefit-Cost ratio for deploying CCTVs on Route 76 for a period of 20 years is obtained as 13.65. Similarly, the results of a sensitivity analysis are summarized in following Table 58.

Table 58. Sensitivity analysis for B/C ratio of CCTV

	Discount rate		Monetary value of time	
	5%	6%	$11/veh-hr	$14/veh-hr
Benefit	$2,278,294	$2,114,564	$2,091,691	$2,662,152
Cost	$171,685	$164,349	$180,216	$180,216
Benefit-cost ratio	13.27	12.86	11.6	14.7

<u>Route 130</u>

The following sections present the benefit cost analysis performed for Route 130:

Benefits of Loop Detectors for Incident Detection

- Total vehicle-hours saved (in case of incident occurrence) in one year due to loop detectors on Route 130 is 22,291 veh-hrs.
- Total average annual benefits rendered due to loop detectors on Route 130 can be calculated as

PVB_k = (veh-hrs saved annually) x (monetary value of time) = $286,606.

- Total average benefits of deploying loop detectors on Route 130 for 20 years can be computed as ($\sum_{k=1}^{20} PVB_k$) = $4,049,743.

Costs of Loop Detectors

84 loop detectors are required for this route. Using the cost estimation equation, the total average cost of deploying loop detectors on Route 130 for 20 years is obtained as, ($\sum_{k=1}^{20} PVC_k$) = $545,473.

Benefit/Cost Ratio of Incident Detection using Loop Detectors

Thus, the benefit-cost ratio for deploying loop detectors on Route 130 for a period of 20 years is obtained as 7.42. The following Table 59 summaries benefit-cost ratios for various discount rates and monetary values of time.

Table 59. Sensitivity analysis for B/C ratio of Loop Detector

	Discount rate		Monetary value of time	
	5%	6%	$11/veh-hr	$14/veh-hr
Benefit	$3,748,806	$3,479,397	$3,464,780	$4,409,720
Cost	$ 510,951	$ 479,871	$545,473	$545,473
Benefit-cost ratio	7.33	7.25	6.35	8.08

Benefits of CCTV for Incident Detection

- Total vehicle-hours saved (in case of incident occurrence) in one year due to CCTVs on route 130 is 26,319 veh-hrs.
- Total average annual benefits rendered due to CCTVs on Route 130 can be calculated as

PVB_k =(veh-hrs saved annually) x (monetary value of time) = $338,392

Using the above values in the benefit estimation formulae yields the total average benefits of deploying CCTVs on Route 130 for 20 years: ($\sum_{k=1}^{20} PVB_k$) = $4,781,481.

Costs of CCTV

Ten CCTVs are required along this route. Using the cost estimation equation the total average cost of deploying CCTVs on Route 130 for 20 years is obtained as,

$(\sum_{k=1}^{20} PVC_k)$ = $600,722.

Benefit/Cost Ratio of Incident Detection Using CCTV

Benefit-Cost ratio for deploying CCTVs on Route 130 for a period of 20 years is obtained as 7.96. Table 60 presents the B/C ratios for various discount rates and monetary values of vehicle-hour.

Table 60. Sensitivity analysis for B/C ratio of Loop Detector

	Discount rate		Monetary value of time	
	5%	6%	$11/veh-hr	$14/veh-hr
Benefit	$4,4261,69	$4,108,080	$4,090,822	$5,206,501
Cost	$ 572,285	$547,830	$600,722	600,722
Benefit-cost ratio	7.73	7.5	6.81	8.67

<u>Route 295</u>

The following sections present the benefit cost analysis performed for Route 295:

Benefits of Incident Detection Using Loop Detectors

- Total vehicle-hours saved (in case of incident occurrence) in one year due to loop detectors on Route 295 is 25,580 veh-hrs.
- Total average annual benefits rendered due to loop detectors on Route 295 can be calculated as

PVB_k =(veh-hrs saved annually) x (monetary value of time) = $328,886.

Using the above values in the benefit estimation formulae yields the total average benefits of deploying loop detectors on Route 295 for 20 years, $(\sum_{k=1}^{20} PVB_k)$ = $4,647,160.

Costs of Loop Detectors

112 loop detectors are needed along this route. Using the cost equation the total average cost of deploying loop detectors on Route 295 for 20 years is obtained as, ($\sum_{k=1}^{20} PVC_k$) =$727,297.

Benefit/Cost Ratio of Incident Detection Using Loop Detectors

The benefit-Cost ratio for deploying loop detectors on Route 295 for a period of 20 years is found as 6.39. Following Table 61 also lists the B/C ratios for various discount rates and monetary values of vehicle-hour.

Table 61. Sensitivity analysis for B/C ratio of Loop Detector

	Discount rate		Monetary value of time	
	5%	6%	$11/veh-hr	$14/veh-hr
Benefit	$4,301,829	$3,992,676	$3,975,904	$5,060,241
Cost	$681,268	$639,828	$727,297	$727,297
Benefit-cost ratio	6.31	6.24	5.47	6.96

Benefits of Incident Detection Using CCTV

- Total vehicle-hours saved (in case of incident occurrence) in one year due to CCTVs on Route 295 is 30,202 veh-hrs.
- Total average annual benefits rendered due to CCTVs on Route 295 can be calculated as

PVB_k =(veh-hrs saved annually) x (monetary value of time)= $388,311.

Using the above values in the benefit estimation formulae yields the total average benefits of deploying CCTVs on Route 295 for 20 years, ($\sum_{k=1}^{20} PVB_k$) =$5,486,844.

Costs of CCTV

Nine CCTVs are needed along this route. Using the cost estimation equation, the total average cost of deploying CCTVs on Route 295 for 20 years is obtained as, ($\sum_{k=1}^{20} PVC_k$) = $540,650.

Benefit/Cost Ratio of Incident Detection Using CCTV

The benefit-Cost ratio of deploying CCTVs on Route 295 for a period of 20 years is obtained as 10.15. Table 62 lists the B/C ratios for various discount rates and monetary values of vehicle-hour.

Table 62. Sensitivity analysis for B/C ratio of CCTV

	Discount rate		Monetary value of time	
	5%	6%	$11/veh-hr	$14/veh-hr
Benefit	$5,079,117	$4,714,104	$4,694,299	$5,974,563
Cost	$515,056	$493,047	$540,650	$540,650
Benefit-cost ratio	9.86	9.56	8.68	11.05

Based on the above analysis, it can be concluded that both loop detectors and CCTVs are feasible and viable incident detection and verification technologies for the South Jersey network and can be effectively used to render substantial long-term benefits in case of incident occurrence.

Benefit/Cost Analysis of VMS for Traffic Management

As seen in Figure 79, there are basically two types of link geometries for which a VMS can be deployed to inform travelers about an incident occurrence. One is a scenario where a single upstream link diverges into two downstream links, and while the other scenario is when two upstream links diverge into two downstream links. Both of the above scenarios were analyzed for VMS deployment and their respective benefit-cost ratios were computed using the simulation model based on the methodology described in previous chapters. The costs of VMS are listed in Table 63.

Table 63. Costs of VMS for freeways [22]

Technology	Unit Capital Cost ($K)		Os & Mt Cost ($K)	
	Low	High	Low	High
VMS	48	120	2.4	6
VMS Tower	25	125		
Portable VMS	21.5	25.5	1.2	2

Following discussion illustrates the results obtained from the analysis:

<u>Scenario 1</u>

The links involved in this scenario are links 21 (upstream link, Rt. 130), 22 (downstream link, Rt. 130), and 24 (downstream link, Rt. 295). VMS is deployed in link 21.

Benefits

- Total vehicle-hours saved (in case of an incident occurrence) by vehicle diversion in the affected links in one year due to VMS in link 21 is 48,626 veh-hrs.
- Total average annual benefits rendered due to VMS on link 21 can be calcualated as

  PVB_k =(veh-hrs saved annually) x (monetary value of time)= $624,855.

Using the above value in the benefit estimation equation yields the total average benefits of deploying VMS on link 21 for 20 years as: ($\sum_{k=1}^{20} PVB_k$) =$8,829,201.

Costs

The type of VMS suggested to be deployed is a full matrix, LED, 3-line, walk-in VMS with a cantilever structure.

- Average annual capital cost of deploying a VMS of the above-mentioned type on corridors is $120,000 (22).
- Average annual operations and maintenance cost of VMS of the above-mentioned type is $6,000 (22).
- Average annual capital cost of constructing a VMS tower for the VMS of the above-mentioned type on corridors is $25,000 (22).
- Lifetime of a VMS of the above-mentioned type is 20 years (22).
- Lifetime of a VMS tower is 20 years (22).

Using the above values in the cost estimation equation yields the total average cost of deploying VMS on link 21 for 20 years as: ($\sum_{k=1}^{20} PVC_k$) = $229,780.

Benefit/Cost Ratio

Benefit-Cost ratio for deploying VMS on link 21 for a period of 20 years is obtained as 38.42. Table 64 also lists the B/C ratios for various discount rates and monetary values of vehicle-hour.

Table 64. Sensitivity analysis for B/C ratio of VMS

	Discount rate		Monetary value of time	
	5%	6%	\$11/veh-hr	\$14/veh-hr
Benefit	\$8,173,103	\$7,585,739	\$7,558,071	\$9,619,363
Cost	\$223,480	\$217,840	\$229,780	\$229,780
Benefit-cost ratio	36.57	34.82	32.89	41.86

<u>Scenario 2</u>

The links involved in this scenario are 6 (upstream link, Rt. 42), 12 (upstream link, Rt. 295), 19 (downstream link, Rt. 76), and 20 (downstream link, Rt. 295). VMS is deployed in link 6 and link 12.

Benefits

- Total vehicle-hours saved (in case of incident occurrence) by vehicle diversion in the affected links in one year due to VMS in link 6 and link 12 is 39,524 veh-hrs.
- Total average annual benefits rendered due to VMS on link 6 and link 12 can be calculated as

PVB_k =(veh-hrs saved annually) x (monetary value of time)=\$507,892.

- Similarly, the average benefits of deploying VMS on link 6 and link 12 for 20 years is $(\sum_{k=1}^{20} PVB_k)$ = \$7,176,526.804

Costs

Using the same type of VMS in scenario 1, plugging the above values in the cost estimation equation yields the total average cost of deploying VMS on link 6 and link 12 for 20 years as: $(\sum_{k=1}^{20} PVC_k)$ = \$459,560.

Benefit/Cost Ratio

Benefit-cost ratio for deploying VMS on link 6 and link 12 for a period of 20 years is obtained as 15.61. Table 65 also lists the B/C ratios for various discount rates and monetary values of vehicle-hour.

Table 65. Sensitivity analysis for B/C ratio of VMS

	Discount rate		Monetary value of time	
	5%	6%	$11/veh-hr	$14/veh-hr
Benefit	$6,643,239	$6,165,819	$6,143,330	$7,818,784
Cost	$446,960	$435,680	$ 459,560	$459,560
Benefit-cost ratio	14.86	14.15	13.37	17.01

<u>Scenario 3</u>

The VMS is installed only in link 12. In the event of an incident in either link 19 or link 20, only vehicles present in link 12 are diverted but the vehicles in link 6 are unaffected by the incident.

Benefits

Total vehicle-hours saved (in case of incident occurrence) by vehicle diversion in the affected links in one year due to VMS in link 12 is 17,745 veh-hrs.

Accordingly, the total average annual benefit resulted due to VMS on link 12 is obtained as $228,026. Using in the above values in the benefit estimation equation yields the total benefit of deploying VMS on link 12. The analysis is done for 20 years and the total benefits are found to be $3,222,012.

Costs

The total average cost of deploying VMS on link 12 for 20 years is obtained as ($\sum_{k=1}^{20} PVC_k$) = $229,780.

Benefit/Cost Ratio

The benefit-Cost ratio for deploying VMS on link 12 for a period of 20 years is 14.02.

Based on the above analysis, it can be concluded that for link geometries corresponding to each of the above type of scenarios in the South Jersey network, variable message signs of this type are an effective incident response technology that can be successfully employed to render substantial long-term benefits in case of an incident occurrence by diverting vehicles away from the incident ridden link to an alternate link.

Benefit/Cost Analysis of FSP

In this section, the effects of freeway service patrol are studied. Three response vehicles are assigned to the depot. Figure 80 demonstrates the relationship between the average incident duration and the number of FSP vehicles. The longest patrolling route is illustrated in Development of Traffic and Incident Response Simulation Model chapter is used.

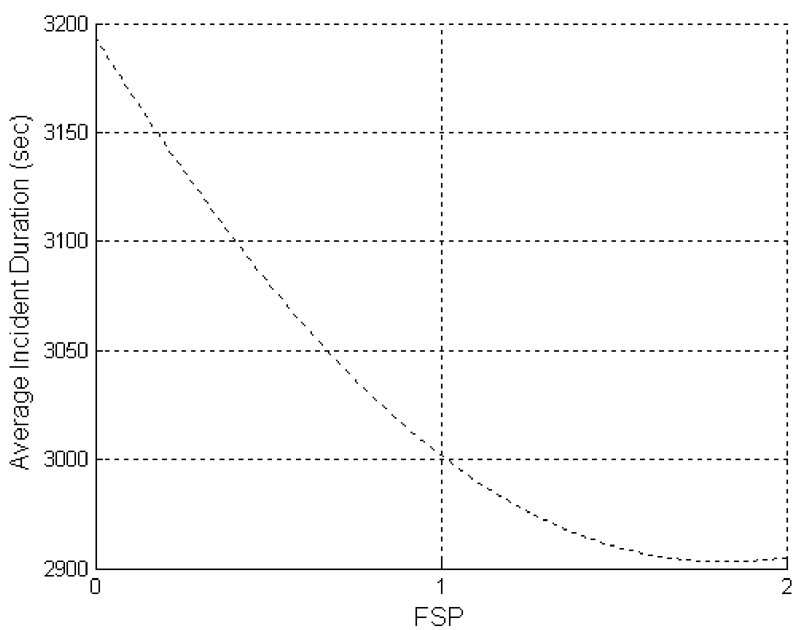


Figure 80. Relationship between the number of FSP vehicles and average incident duration with three response vehicles at the depot

Benefit/Cost Analysis

Vehicle-Hour Saved By Patrolling Service

From Figure 80, deploying one FSP vehicle reduces the incident duration by 200 seconds. According to the ITE Journal [39], each minute of incident duration results in four to five minutes of additional delay. Thus travel time saved by FSP would be approximately 1000 seconds.

It is assumed that 100 vehicles benefit from such a reduction of incident duration. Referring to South Jersey incident database, there are around 785 emergency incidents occurred in the year 2000. Thus the total number of vehicle-hours saved is

$$785\,[incidents] \times 1000\,[sec/incident] \times 100\,[veh]\,/\,3600\,[sec/hour] = 2.1 \times 10^4 [veh - hour]$$

.

Quantification Of Benefits

According to Wilbur Smith Associates [40], the monetary value of time (including the user cost savings related to lost travel time or delay savings per year and savings in lost fuel cost per year) saved in terms of vehicle-hours is $12.85/veh-hr. So, the total money saved by adding one FSP vehicle would be $\$12.85 \times 2.1 \times 10^4 = \$2.7 \times 10^5$.

Quantification Of Costs

Referring to *TransCore ITS Planning Handbook*, unit capital cost of a special tow truck is $50k, annual operation & maintenance cost is $2.5k each year, annual operation & maintenance personnel cost is $50k, annual communication cost and others are around $500.

Annual Equivalent Criterion is used to compute the annual cost. The concept and the method can be found in Canada et al [41]. It is assumed the tow truck is estimated to have a lifetime of ten years, and a zero market value at that time. A

MARR (Minimum Attractive Rate of Return) of 10% is used. Then, the annul cost of a tow truck can be computed as

$$Annual_{investment} = \$50000 \times \left[\frac{0.1 \times (1+0.1)^{10}}{(1+0.1)^{10} - 1} \right] = \$8137.3 .$$

Thus, the total annual cost is

$$Annual_{cost} = Annual_{investment} + Annual_{operation+maintenance} = \$8137.3 + \$50000 + \$3000 = \$6.1 \times 10^{4} .$$

Benefit/Cost Ratio

Finally, the benefit/cost ratio could be computed as

$$b / c\ ratio = \$2.7 \times 10^{5} / \$6.1 \times 10^{4} = 4.42 .$$

Marginal Benefits

If one more FSP vehicle is added, it can be seen from Figure 80 that the average incident duration would be reduced by 290 seconds in total. Accordingly, the total number of vehicle-hours saved is

$$785\,[incidents] \times 1450\,[sec / incident] \times 100\,[veh] / 3600\,[sec / hour] = 3.0 \times 10^{4} [veh - hour]$$

So, the total money saved can be computed as

$$\$12.85 \times 3.0 \times 10^{4} = \$3.85 \times 10^{5} .$$

Thus, the marginal benefit by adding the second FSP vehicle is

$$\frac{\$3.85 \times 10^{5} - \$2.7 \times 10^{5}}{2 - 1} = \$1.15 \times 10^{5} .$$

The benefit/cost ratio for the second FSP vehicle would be 1.89, which is much smaller than the first deployed FSP vehicle. The overall benefit/cost ratio for these two FSP vehicles is 3.2.

CONCLUSIONS

The benefit cost analysis for all the incident technologies is done for a period of 20 years, thus taking into account the long-term benefits of their respective implementation. Results of the analyses show that loop detectors and CCTVs are viable options for incident detection and hence these detection technologies are worth implementing in the South Jersey corridor. In fact, loop detectors and CCTVs have always proven to be useful in incident detection, as supported by several studies that have been conducted over the years to analyze the effectiveness of these technologies. For example, the TransGuide system implemented in San Antonio, Texas, involves the usage of loop detectors and CCTVs among many other incident management technologies. The system reported a reduction in primary accidents by 35%, secondary accidents by 30%, inclement weather accidents by 40%, and overall accidents by 41% (22). A review of video surveillance/CCTV data collected throughout 1995 indicated an average reduction in response time of 20%. Using the accident frequency for freeways, the results showed an annual savings of $1.65 million. Another instance of the successful usage of loop detectors and CCTVs is observed in the traffic management system for Highway 401 in Metropolitan Toronto known as COMPASS (25). COMPASS is developed to provide safe and efficient travel on 42 km of the highway. It consisted of CCTV cameras and loop detectors for monitoring highways and determining traffic speed, volume, and density and for detecting incidents. Incident conditions and delay information were sent to variable message signs, the media, faxes, and radio stations to enable motorist to choose alternative routes. The system reduced average incident duration from 86 minutes to 30 minutes per incident.

Table 66. Benefit/cost ratios for loop detectors and CCTV for incident detection

Routes	Loop Detectors	CCTVs
76	5.35	13.65
130	7.42	7.96
295	6.39	10.15

The benefit cost ratios obtained for VMS from the analysis were also substantial, and hence it can be inferred that deploying VMS in the South Jersey network is also a sustainable option. Again, there have been numerous studies focusing on the benefits and costs of VMS, most of which have found VMS to be beneficial in reducing the traffic delays from incidents as well as in reducing secondary incidents. For example, a simulation study is conducted to determine the impact of a freeway management system on incident-related congestion in Fargo, North Dakota [(42)]. The highway network investigated in this study consisted of the area surrounding the intersection of Interstates 29 and 94 in Fargo. Included in the study area were four of the area's most heavily traveled arterials, providing travelers with alternative routes for diversion around the incident, which is simulated to occur in the northbound lanes of I-29 just north of the intersection with I-94. Results of the investigation indicated that a freeway management system consisting of variable message signs to alert motorists of upcoming incidents can have a significant positive impact on freeway operations in a city of moderate size, such as Fargo. Simulation revealed an 8% decrease in network travel times and an 8% increase in speeds with the installation of the VMS signs.

Table 67. Benefit Cost ratios for VMS for traffic management during non-recurrent congestion

Scenario	VMS
1	38.42
2	15.61

A sensitivity analysis is also conducted for all the scenarios to reflect the effect of varying the assumed parameters like discount rate, monetary value of time etc. on the benefit cost ratios. Based on the simulation results, it is concluded that the use of freeway service patrol is an important strategy to improve incident management. The benefit/cost ratio of the freeway service patrol is estimated to be 4.5. For an additional patrol vehicle, its marginal benefit/cost is calculated as 1.89. The sensitivity analysis also demonstrated the impact of deploying VMS in only one of the upstream links, and the benefits rendered by VMS were still feasible. Based on the recommendations provided in this report, the chosen incident management technologies can be successfully employed in the South Jersey network to substantially decrease the lost vehicle-hours and travel-time delays, increase throughput, and hence increase the overall efficiency of the network. However, it should be kept in mind that these are preliminary results based on various assumptions and more detailed studies are needed to further improve the reliability of these results.

The developed simulation model, RIMS, can also be used with other traffic networks and the results obtained from the model can be used for simple traffic engineering analyses, such as traffic prediction over networks. Future work on this study can involve analyzing the effect of a variable traffic demand on the benefit cost ratios.

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APPENDIX A – INCIDENT DURATION MODELS

MVA (Motor Vehicle Accident)

a. Daytime with blocked lanes (154 data points, mean = .749 hour, std deviation = 0.631)

Model: *Lognormal*(theta=0, zeta=-.58, sigma=.778)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.1877092		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.7054465		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	3.3419850		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	25.7362743	4	Pr > Chi-Sq	<0.001

b. Daytime without blocked lanes (223 data points, mean = .928 hour, std deviation = 0.61)

Model: *Lognormal*(theta=0, zeta=-.301, sigma=.725)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.1948342		Pr > D	<0.010
Cramer-von Mises	W-Sq	1.1136822		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	5.7046058		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	68.6590459	4	Pr > Chi-Sq	<0.001

c. Night-time with blocked lanes (39 data points, mean = .832 hour, std deviation = 0.714)

Model: *Lognormal*(theta=0, zeta=-.485, sigma=.791)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.1419749		Pr > D	0.046
Cramer-von Mises	W-Sq	0.1479604		Pr > W-Sq	0.024
Anderson-Darling	A-Sq	0.7839038		Pr > A-Sq	0.040
Chi-Square	Chi-Sq	19.9250422	4	Pr > Chi-Sq	<0.001

d. Night-time without blocked lanes (27 data points, mean = .837 hour, std deviation = 0.507)

Model: *Lognormal*(theta=0, zeta=-.367, sigma=.668)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.16874730		Pr > D	0.047
Cramer-von Mises	W-Sq	0.14730191		Pr > W-Sq	0.024
Anderson-Darling	A-Sq	0.86363282		Pr > A-Sq	0.023
Chi-Square	Chi-Sq	6.37345553	2	Pr > Chi-Sq	0.041

Disablement

a. Disablement with blocked lanes (24 data points, mean = .742 hour, std deviation = 0.679)

Model: *Lognormal*(theta=0, zeta=-.626, sigma=.818)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.19939185		Pr > D	0.015
Cramer-von Mises	W-Sq	0.12405365		Pr > W-Sq	0.049
Anderson-Darling	A-Sq	0.62463218		Pr > A-Sq	0.094

Chi-Square	Chi-Sq	7.65494480	4	Pr > Chi-Sq	0.105

b. Disablement without blocked lanes (11 data points, mean = .682 hour, std deviation = 0.323)

Model: *Lognormal*(theta=0, zeta=-.497, sigma=.518)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.19468355		Pr > D	>0.150
Cramer-von Mises	W-Sq	0.08540556		Pr > W-Sq	0.160
Anderson-Darling	A-Sq	0.49894751		Pr > A-Sq	0.171

Weather-related (15 data points, mean = 1.887 hour, std deviation =0.966)

Model: *Normal*(1.89, .97)

Goodness-of-fit:

Goodness-of-Fit Tests for Normal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.14668318		Pr > D	>0.150
Cramer-von Mises	W-Sq	0.06387479		Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.46652417		Pr > A-Sq	0.223
Chi-Square	Chi-Sq	3.78399865	1	Pr > Chi-Sq	0.052

Vehicle fire (44 data points, mean = 0.665, std deviation = 0.383)

Model: *Lognormal*(theta=-1, zeta=.487, sigma=.212)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.28570971		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.48426091		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	2.33041612		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	2.86365825	2	Pr > Chi-Sq	0.239

HAZMAT (31 data points, mean = 1.077, std deviation = 0.723)

Model: *Normal*(1.077, .723)

Goodness-of-fit:

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.15554438		Pr > D	0.054
Cramer-von Mises	W-Sq	0.10893787		Pr > W-Sq	0.085
Anderson-Darling	A-Sq	0.68479591		Pr > A-Sq	0.070
Chi-Square	Chi-Sq	0.46153650	2	Pr > Chi-Sq	0.794

APPENDIX B - NUMBER OF LANES BLOCKED FOR EACH INCIDENT TYPE

HAZMAT

Ratio of lanes blocked	Percentage
0	67.74%
0.33	6.45%
0.66	16.13%
1	9.68%

Vehicle-fire

Ratio of lanes blocked	Percentage
0	44.90%
0.25	10.20%
0.33	32.65%
0.5	6.12%
1	6.12%

Weather

Ratio of lanes blocked	Percentage
0	65.38%
0.33	11.54%
1	23.07%

Disablement-Blocked Lanes

Ratio of lanes blocked	Percentage
0.25	34.48%
0.33	34.48%
0.5	17.24%
1	13.79%

MVA-Day Time-Blocked Lanes

Ratio of lanes blocked	Percentage
0.25	14.13%
0.33	28.80%
0.5	22.28%
0.66	13.04%
1	22.28%

MVA-Night Time-Blocked Lanes

Ratio of lanes blocked	Percentage
0.25	21.56%
0.33	35.29%
0.5	25.49%
1	17.65%

APPENDIX C - MAIN C ++ CLASSES

Name	Corresponding file
TmainFrame	Main.h main.cpp
Tdepot	Depot.h depot.cpp
TserviceVehicle	serviceVehicle.h serviceVehicle.cpp
TaccidentGeneration	AccidentGen.h AccidentGen.cpp
TpatrolService	PatrolService.h PatrolService.cpp

Class Name	**TaccidentGeneration**	
Description	Dealing with incident generation.	
Member Variables		
Name	Type	Description
PoliceNumber	Integer	Number of police cars requested by an incident.
PoliceWorkload	Integer	How long need a police car to be onsite.
AmbuNumber	Integer	Number of ambulances requested by an incident.
AmbuWorkload	Integer	How long need an ambulance to be onsite.
TowNumber	Integer	Number of tow trucks requested by an incident.
TowWorkload	Integer	How long need a tow truck to be onsite.
FireNumber	Integer	Number of fire trucks requested by an incident.
FireWorkload	Integer	How long need a fire truck to be onsite.

EmsNumber	Integer	Number of EMS requested by an incident.
EmsWorkload	Integer	How long need an EMS vehicle to be onsite.
NactualNumber	Integer	The number of generated incidents.
NExpectedIncident	Integer	The expected number of incident in the simulation period.
NnodeNumber	Integer	Number of nodes in the roadway network.
FSimulationTime	Integer	The length of the simulation period.
MatrixInc	Array	An array used to store the information of the generated incident.
Member Functions		
Name	Return Type	Description
WriteLog(int replication)	Void	Write the incident generating process into a text file.
Generate(bool bUseHistoricData)	Void	Generate incident in accordance with a given distribution or based on historical incident data.
GenerateIncidentFromDatabase()	Void	Generate incident from historical incident data.
GenerateByNormalDist(int level)	Void	Generate the duration for different TFRUs in accordance with Normal distribution, given the priority level of this incident.
GeneratePriorityByPercent()	Void	Generate the priority level of the incidents.
GenerateOccurenceTime()	Void	Generate the occurrence time of the incidents.

GeneratePoliceCar()	Void	Generate the number and workload of police cars.
GenerateTowTruck ()	Void	Generate the number and workload of tow trucks
GenerateAmbulance ()	Void	Generate the number and workload of ambulances.
GenerateFireTruck ()	Void	Generate the number and workload of fire trucks.
GenerateEMS ()	Void	Generate the number and workload of EMS.

Class Name	Tdepot	
Description	Describe the properties and activities of the depot.	
Member Variables		
Name	Type	Description
Location	Integer	The node where the depot is constructed.
TfruType	Integer	What type of TFRU does this depot have.
TfruNumber	Integer	The number of TFRU in this depot.
IdleTfru	Integer	The number of idle TFRUs.
Identity	Integer	The identification number of this depot.
Activity	Integer	An index number used to record the activities.
Tfru	Array	An TserviceVehicle array used to describe the status of each service vehicle in this depot.
Member Functions		
Name	Return Type	Description
GetIdentity()	Integer	Get the id of this depot.
GetIdleTfru()	Integer	Return the number of idle service vehicles.
GetLocation()	Integer	Return the location of this depot.
GetTfruType()	Integer	Return the type of the service vehicle of this depot.
GetName ()	String	Return the name of this depot.
GetTfruNumber ()	Integer	Return the number of the service vehicle of this depot.
SetIdleTfru ()	Void	Set the number of idle service vehicles of this depot.
SetLocation ()	Void	Set the location of this depot.
SetTfruType ()	Void	Set the type of the service vehicles of this depot.
SetName ()	Void	Set the name of this depot.

SetTfruNumber ()	Void	Set the number of service vehicles assigned to this depot.
Reset ()	Void	Reset the status of this depot.
WriteLog ()	Void	Write the activity log.
UpdateLog ()	Void	Update the activity log.

Class Name	TserviceVehicle	
Description	The status and activities of each service vehicle.	
Member Variables		
Name	Type	Description
DepotID	Integer	Belong to which depot.
depotLocation	Integer	The location of the depot.
Activity	Integer	Status of the service vehicle. 0-idle, 1-busy.
dispatchTime	Integer	When is this service vehicle dispatched from its depot.
waitingTime	Integer	The waiting time (the time between the detection of the incident and this vehicle is dispatched) of this service vehicle.
arrivalTime	Integer	When the service vehicle arrive the site of the incident.
serviceTime	Integer	How long have the service vehicle stay on site.
TravelTime	Integer	How long does it take to travel from its current location to the site of the incident.
Accident	Integer	Which incident the service vehicle is assigned to.
FinishTime	Integer	The time when the service vehicle leave the site of the incident for its depot.
Member Functions		
Name	Return Type	Description
Reset()	Void	Reset the status of this service vehicle.

Class Name	**TpatrolService**	
Description	Deal with patrol service.	
Member Variables		
Name	Type	Description
Head	NODE	The head of the double linked list which define the patrolling route.
VehiclesNumber	Integer	Number of service vehicles in this patrolling fleet.
RouteName	String	The name of the patrolling route.
Status	Integer	Status of the patrolling route. 0-disabled, 1-enabled.
StartingNode	Integer	From where the vehicles resume patrolling.
origin_startingNode	Integer	The original given starting point.
StartingTime	Integer	When do the vehicles resume patrolling.
Activity	Integer	An index number used to record the activities.
ActivityLog	Array	Recording the activity of the patrolling fleet.
Member Functions		
Name	Return Type	Description
GenerateRoute(String path)	NODE	Generate a double linked list to describe the route given by a string, and return the head of the linked list.
GetLocation(int when)	Integer	Return the location of the patrolling unit at any time.
GetTravelTime(int destination, int setoutTime)	Integer	Get the current location time *setoutTime*, then calculate the travel time from current location to the destination.
UpdateLocation(int currentLocation, int current)	Void	Reset the location of the patrolling unit at time *current*.
GetTheNode(int nodeNumber)	NODE	Return the node with key value equal to

nodeNumber)		*nodeNumber*.
Reset ()	Void	Reset the status of this patrolling route.
WriteLog(int activity, int towhere, int request)	Void	Record the activities of the patrolling service.

APPENDIX D - DESCRIPTION OF INPUT AND OUTPUT FILES FOR TRAFFIC SIMULATION

Input Files

There are 4 types of input files required by our traffic simulation module:

- Parameter file
- Link file
- Incident file
- Incident location file

Following is a brief description of all the above input data files.

Parameter File

Sample Parameter file

<1> 5 1000 3600 100 3500
<2> 70 20
<3> 0.9 0.8 0.7 0.6 0.5 0.3 0.1
<4> 1 1000 6 1
<5> 2 1000 11 1
<6> 3 1000 12 1

Description of parameter file

Line	Field	Description
1	1	Number of origin nodes in the network (also the number of origin node descriptor records to be read in from the file) [integer]
	2	Length of a cell of the *Cell Transmission Model* (feet) [real] Distance traversed by a vehicle traveling with free speed on a link in one simulation time interval ≤ x ≤ minimum length of a link of the given network
	3	Total time for which the simulation will run (seconds) [integer]
	4	Start time of the time interval for which the average travel time for the links of the network is desired (seconds) [integer] 0 ≤ x ≤ Total Simulation Time (field 3)
	5	End time of the time interval for which the average travel time for the links of the network is desired (seconds) [integer] 0 ≤ x ≤ Total Simulation Time (field 3)
2	1	Percentage of cellular phone users among the travelers [real]
	2	Maximum (threshold) number of cellular phone calls to be received before the incident is assumed to be verified [integer]
3	1	Proportion of the split ratio of traffic remaining in the incident ridden following link of a diverge link for an incident severity level* of 1 [real]
	2	Proportion of the split ratio of traffic remaining in the incident ridden following link of a diverge link for an incident severity level* of 2 [real]
	3	Proportion of the split ratio of traffic remaining in the incident ridden following link of a diverge link for an incident severity level* of 3 [real]
	4	Proportion of the split ratio of traffic remaining in the incident ridden following link of a diverge link for an incident severity level* of 4 [real]
	5	Proportion of the split ratio of traffic remaining in the incident ridden following link of a diverge link for an incident severity level* of 5 [real]

	6	Proportion of the split ratio of traffic remaining in the incident ridden following link of a diverge link for an incident severity level* of 6 [real]
	7	Proportion of the split ratio of traffic remaining in the incident ridden following link of a diverge link for an incident severity level* of 7[real]
4+	1	Identification number of the origin node [integer]
	2	Traffic demand going in the network from this node (veh/hour) [real]
	3	Identification number of the downstream node of the link of which *field 1* is the origin node
	4	Proportion of the traffic demand (*field 2*) going into *field 3* [real] $0.0 \leq x \leq 1.0$ Note : Repeat fields 3 and 4 in this order till all the links of which *field 1* is the origin node are read.

* Incident severity level increases from 1 to 7,with 1 being the least severe and 7 most severe.

Link File

Sample Link file

<1> 31 29 1 1

<2> 1 1 6 55 432 3.45 5400 1 0 0 0 3 0 1 0

<3> 2 6 7 55 432 1.12 5400 0 0 0 0 3 0 0 1

<4> 3 7 8 55 432 1.37 5400 0 0 0 0 3 0 0 0

<5> 4 8 9 55 576 0.63 7200 0 0 0 0 4 0 1 1

<6> 5 9 10 55 576 0.87 7200 0 0 0 0 4 0 1 0

<7> 6 10 18 55 864 0.51 10800 0 0 0 1 6 1 0 1 19 0.5 20 0.5

<8> 7 2 11 40 260 1.0 3000 1 0 0 0 2 0 0 0

<9> 8 11 12 40 260 0.8 3000 0 0 0 1 2 1 0 1 10 0.5 11 0.5

<10> 9 3 12 55 432 2.36 5400 1 0 0 1 3 1 0 1 10 0.5 11 0.5

<11> 10 12 13 55 432 1.88 5400 0 0 1 0 3 0 1 1 8 0.5 9 0.5

<12> 11 12 16 40 130 3.72 1500 0 0 1 0 1 0 1 1 8 0.5 9 0.5

<13> 12 13 18 55 432 1.07 5400 0 0 0 1 3 1 0 0 19 0.5 20 0.5

<14> 13 4 14 40 260 1.26 3000 1 0 0 0 2 0 1 1

<15> 14 14 15 40 390 1.60 4500 0 0 0 1 3 0 0 1 16 0.5 31 0.5

<16> 15 5 15 40 260 3.56 3000 1 0 0 1 2 0 1 1 16 0.5 31 0.5

<17> 16 15 16 40 260 1.12 3000 0 0 1 0 2 0 1 1 14 0.5 15 0.5

<18> 17 16 17 40 260 1.10 3000 0 0 1 0 2 0 0 0 11 0.5 16 0.5

<19> 18 17 19 40 260 1.19 3000 0 0 0 1 2 1 0 1 26 0.5 27 0.5

<20> 19 18 19 55 720 0.97 9000 0 0 1 1 5 1 0 0 6 0.5 12 0.5 26 0.5 27 0.5

<21> 20 18 20 55 720 1.0 9000 0 0 1 0 5 0 0 1 6 0.5 12 0.5

Description of link file

Line	Field	Description
1	1	Total number of links in the network (also the number of link descriptor records to be read in from the file) If x = 0 then no records would be read in
	2	Total number of nodes in the network
	3	Variable determining if the user wants to compare current simulation results with those for future runs or not [integer] x = 1, if the user wants to do a comparison x = 0, if the user does not want to do a comparison
	4	Scale factors for free-speed
2+	1	Unique link identification number [integer] 1 ≤ x ≤ Max. # of links in network
	2	Identification number of the node at the upstream end of the link [integer]
	3	Identification number of the node at the downstream end of the link [integer]
	4	Free speed on the link (miles/hr) [real]
	5	Jam density (veh/mil) [real]
	6	Link length (miles)
	7	Basic free flowing saturation flow rate (veh/hour) [real]
	8	Variable describing origin characteristics of upstream node [integer] x = 1, if upstream node is an origin node x = 0, if upstream node is not an origin node
	9	Variable describing destination characteristics of downstream node [integer] x = 1, if downstream node is a destination node x = 0, if downstream node is not a destination node
	10	Variable describing merge characteristics of upstream node [integer] x = 1, if upstream node is a merge node x = 0, if upstream node is not a merge node

	11	Variable describing diverge characteristics of downstream node [integer] x = 1, if downstream node is a diverge node x = 0, if downstream node is not a diverge node
	12	Number of lanes present in the link [integer]
	13	Variable stating whether there is a VMS (variable message sign) in this link or not [integer] x = 1, if there is a VMS in the link x = 0, if there is no VMS in the link
	14	Variable stating whether there is a loop detector in this link or not [integer] x = 1, if there is a loop detector in the link x = 0, if there is no loop detector in the link
	15	Variable stating whether there is a CCTV (close circuit television) in this link or not [integer] x = 1, if there is a CCTV in the link x = 0, if there is no CCTV in the link
	16	Link ID of the first link which is merging into this link [integer]
	17	Proportion of vehicles coming into this link from the link specified in field 16 [real] $0 \le x \le 1$ Continue repeating fields 16 and 17 in this order till all the links merging into this link are specified, then proceed to next field Let, n = number of merge links for this link
	16+(2*n)	Link ID of the first link into which this link diverges [integer]
	17+(2*n)	Proportion of vehicles going from this link to the link specified in field 16+(2*n) [real] $0 \le x \le 1$ Continue repeating fields 16+(2*n) and 17+(2*n) in this order till all the links into which this link diverges are specified

Incident File

Sample incident file

<1> 5

<2> 1 2 1.8 700 1200

<3> 2 5 0.5 900 1500

<4> 3 10 1.5 1200 2500

<5> 4 20 1.0 1500 3500

Description of incident file

Line	Field	Description
1	1	Number of incident descriptor records to be read in from the file [integer] If x = 0 then no records would be read in
2+	1	Incident record number [integer]
	2	Identification number of the link at which the incident will occur on [integer] The exact location of incident occurrence is automatically generated by the program randomly to be somewhere in the link
	3	Effective number of lanes blocked by the incident [real] ≤ x ≤ number of lanes existing on this link
	4	Simulation time at which incident is to begin (seconds) [integer]
	5	Simulation time at which incident is to end (seconds) [integer]

Incident Location File

Sample Incident Location file

<1> 0
<2> 0
<3> 0
<4> 0
<5> 0

Description of incident Location file

Line	Field	Description
1+	1	Incident record number [integer]
	2	Cell number in which the incident occurred [integer]

Note: Initially the cell numbers for all incidents are entered as zero, then if the user wishes to compare the results of the current simulation run with the results of other simulation runs to be performed in the future, then the program updates this file and the actual cell numbers are written in it for each incident.

Output Files

There are five output files generated by this traffic simulation module:

- Travel Time output file
- Incident detection output file
- Averaged Travel Time output file
- Averaged Link Density output file
- Average Link Vehicle Outflow file

Following is a brief description of the above files.

Travel Time File

Sample Travel Time output file

```
<1>   1     241.8009
<2>   2      80.2858
<3>   3      96.0268
<4>   4      43.2482
<5>   5      60.1943
<6>   6      34.6504
<7>   7     101.9665
<8>   8      84.3164
<9>   9     165.8887
<10>  10    143.8704
<11>  11    1185.4817
<12>  12     80.9795
<13>  13    128.8283
<14>  14    156.8431
<15>  15    365.0262
<16>  16    118.9753
<17>  17    119.1798
<18>  18    123.1370
<19>  19     66.7535
<20>  20     68.8829
<21>  21     26.2270
<22>  22     97.4199
```

Description of travel time file

Line	Field	Description
1+	1	Link Identification Number [integer]
	2	Average travel time of this link for the time period specified in the input parameter file (seconds) [real]

Incident Detection Output File

Sample Incident Detection output file

<1>	1	100.00	385.06	310.00	8.56
<2>	2	100.00	297.17	220.00	8.21
<3>	3	100.00	294.61	260.00	7.42
<4>	4	100.00	1045.09	460.00	7.67

Descriptions of incident detection file

Line	Field	Description
1+	1	Incident Identification Number [integer]
	2	Simulation time at which incident is to begin (seconds) [integer]
	3	Incident detection time based on loop detector and CCTV data (seconds) [real]
	4	Incident detection time based on cellular phone calls (seconds) [integer]
	5	False alarm rate (%)

Average Travel Time File

Description of average travel time file

Line	Field	Description
1	1	Time heading [text]
	2+	Link heading [text]
2+	1	Simulation time (seconds) [integer]
	2+	Travel time of the link averaged over the last 1 minute interval (seconds) [real]

Link Density File

Description of link density file

Line	Field	Description
1	1	Time heading [text]
	2+	Link heading [text]
2+	1	Simulation time (seconds) [integer]
	2+	Vehicular link density averaged over the last 1 minute interval (veh/mile) [real]

Average Link Vehicle Outflow

Description of average link vehicle outflow file

Line	Field	Description
1	1	Time heading [text]
	2+	Link heading [text]
2+	1	Simulation time (seconds) [integer]
	2+	Vehicular link outflow averaged over the last 1 minute interval (veh) [real]