Evaluation of incident management strategies and technologies using an integrated traffic/incident management simulation

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Abstract: This paper describes Rutgers Incident Management System (RIMS) software that is developed to evaluate the benefits of various incident management strategies and technologies. This tool can generate incidents and test various response strategies and technologies. South Jersey highway network is used as a test network due to the available historical incident data. The evaluated incident management strategies include the deployment of Variable Message Signs (VMS) to divert traffic during incidents and the use of Freeway Service Patrols (FSPs) for detecting and verifying incidents efficiently. The simulation-based evaluations also include the effect of cellular phone users in the network on the incident detection and verification times. The results show that the studied incident management strategies have positive impacts on reducing incident durations while being cost effective. More specifically, the deployment of VMS for diverting traffic in case of an incident results in a benefit cost ratio of 9.2:1; an additional service unit in freeway patrol results in reduced incident detection and verification time with a corresponding benefit-cost ratio of 3.9:1.

Keywords: incident management; simulation; freeway patrol; evaluation.

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1 Introduction

Traffic congestion is classified as *recurrent* and *non-recurrent*. Recurrent congestion implies the time loss in the routine peak hour traffic due to insufficient roadway capacity. Non-recurrent congestion, on the other hand, is caused by traffic incidents, such as vehicle disablements, cargo spills and accidents. Nationally, highway incidents are estimated to account for approximately 60% of the vehicle-hours lost to congestion (Cambridge Systematics, 1990). Thus, it is clear that congestion is not solely attributable to insufficient infrastructure capacity. The portion due to incidents can be minimised by the use of available resources under a well-managed incident policy.

Incident management is a combination of policies and strategies that effectively coordinates the available resources to reduce incident durations. A well-organised incident management operation restores the traffic flow with the least cost in terms of vehicle delays. Incident management operations can be classified as *network related* and *incident related*.

- Network related operations include the preparation of all available units in case of incident occurrence. The agencies engaged in incident management are highway patrols, department of transportation, Freeway Service Patrols (FSPs), fire departments and ambulances. For instance, determining the routes of patrolling units, the locations of each emergency depot and finding the critical locations to install surveillance cameras are important components of network related operations.

- On the other hand, incident related operations imply all the actions to be taken *during* the incident. Determining the responsible agencies, the required equipments and the proper order of the actions, providing the ease of communication and coordination among participating agencies are the components of incident related operations.

1.1 Objectives

This paper describes the Rutgers Incident Management System (RIMS) software that is developed to evaluate the benefits of various incident management strategies and technologies. RIMS software uses a realistic traffic simulation model based on the cell transmission model proposed by Daganzo (1993). 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. The southern New Jersey highway network is selected for evaluating various incident management strategies due to the available historical incident data.

Section 2 presents background information on incident management. Section 3 presents the related studies in the literature. Section 4 describes the development of traffic and incident response simulation model. Various incident management strategies are tested using the developed computer model. These analyses are presented in Section 5. Finally, Section 6 presents the summary of results with benefit cost analysis of the evaluated incident management strategies.

2 Background information

Incidents can be categorised as accidents, vehicle breakdowns, spilled loads or any other events that reduce the roadway capacity. Quick detection, response and removal of incidents are essential to maximising 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.

The incident management process can be characterised as a set of activities that fall into the four major categories namely, detection, verification and validation, clearance and traffic management. The following sections briefly describe these categories along with technological solutions that are used to improve these individual steps.

2.1 Incident detection

Incident detection is the process by which an incident is first identified by the agencies involved in incident management. The technological methods commonly used to detect and verify incidents include

- mobile telephone calls from motorists initiated by motorists in the vicinity of the incident
- Closed Circuit TV cameras viewed by traffic operators (CCTVs)
- traffic detectors (e.g. video imaging, loop or radar detectors) combined with incident detection software
- Automatic Vehicle Identification (AVI) combined with incident detection software
- motorist aid telephones or call boxes
- police and service patrols
- aerial surveillance
- in-vehicle technologies such as GM's On-Star

2.2 Incident verification

Incident verification is 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. Most commonly used technological solutions used for incident verification include the following:

- CCTV cameras viewed by operators at the traffic control center
- Police or service patrols dispatched to the incident site
- communications by the police, the media or a private information service provider
- combining information from multiple cellular phone calls initiated by motorists in the vicinity of the incident.

2.3 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 popular technological solutions employed for incident response are as follows:

- Computer-Aided Dispatch (CAD)
- service patrol fleets
- towing and recovery vehicles
- fire engines
- rescue units/ambulances
- major incident response teams
- HAZMAT response units
- Changeable Message Signs (CMS)
- traffic responsive arterial signal control.

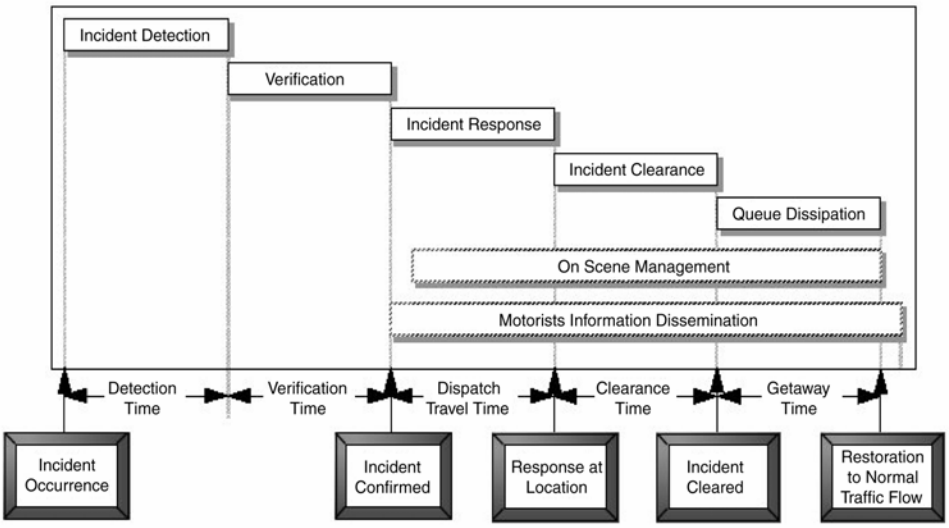
2.4 Incident clearance

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 preincident 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 multiagency process with a single objective under the incident command structure approach – to safely remove roadway obstructions and restore the flow of traffic.

As shown 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. On-scene traffic management (which involves site management and traffic management) and motorist information dissemination start during the incident response phase and continues throughout the duration of incident's impact.

Figure 1 Temporal distributions of incident management phases[1]



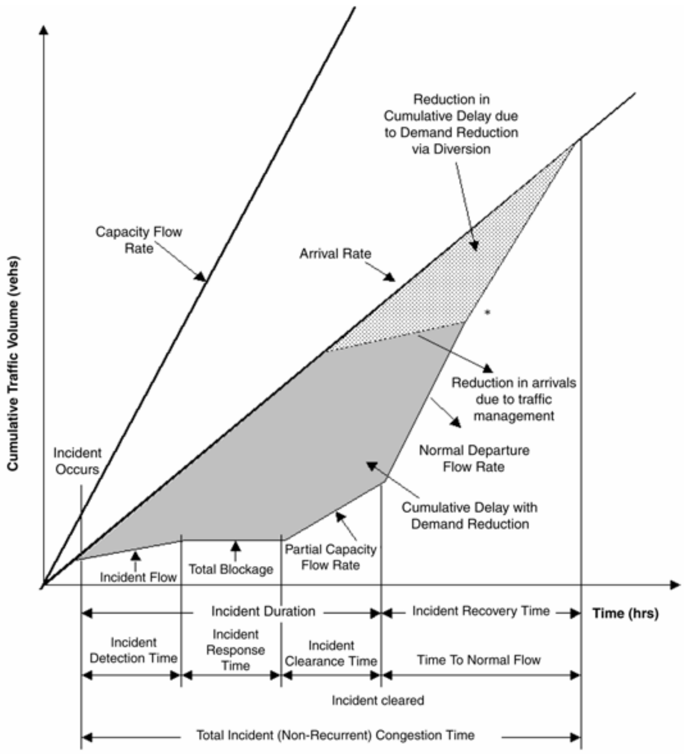
[1]Based on Cambridge Systematics (1990) *Incident Management*, Alexandria, VA: Trucking Research Institute.

[2]Ozbay, K. and Kachroo, P. (1999) *Incident Management for Intelligent Transportation Systems (ITS)*, Massachusetts: Artech House.

2.5 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 flow rates for both arrivals and departures. 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 queued at the upstream of 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 then 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[1]



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

Source: Cambridge Systematics (1990) Incident Management, Alexandria, VA: Trucking ResearchInstitute.

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 based on the definitions given in the Cambridge Systematics report [0]:

1 *Detection time* (t_n): this is the time between the occurrence of the incident occurrence until the time that agencies become aware of the incident.

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 td = 0. Otherwise, td equals to the waiting time until a service vehicle becomes available. Dispatch time will 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 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.

It is apparent that any reduction in detection, response, and clearance time reduces the total incident duration. This, of course, makes the use of effective technological solutions even more important.

3 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. (1998) investigate the effectiveness of FSPs 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 (1991) 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. (2000) 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. (1994) 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.

Ozbay and Kacroo (1999) describe major phases of the incident management operations with an emphasis on the Wide-Area Incident Management Decision Support Software (WAIMSS) developed by Wei et al. (1998) and Ozbay et al. (2005). WAIMSS is one of the first attempts to develop a software package that combines the strengths of experts systems with the mapping capabilities of geographical information (GIS). WAIMSS employed is implemented as a client-server application that adopted a blackboard architecture to enable multiagency cooperation for the most efficient real-time incident management operations. WAIMSS was also validated using real world data (Ozbay and Kachroo, 1998).

There have also been several theoretical studies to analyse the impact of various incident management strategies. Computer simulation is a useful approach to conduct such studies. Liu and Hall (2000) develop a simulation programme (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, FSP trucks, tow trucks operating from fixed bases, highway maintenance vehicles and fire trucks. To focus on dispatching policies, INCISIM utilises 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 (2003) 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 generalise these results to other networks. In terms of incident response, lots of mathematical models have been introduced in the literature. Zografos et al. (1993) proposes an analytical framework that can minimise 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 minimise 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. (1993) is shown to be an effective tool that can model and evaluate the effects of deployment of TFRU on overall freeway incident delays. Later, Sherali and Subramanian (1999) and Ozbay et al. (2004) both proposed probabilistic analytical models that developed to determine best FSP deployment policies in the presence of uncertainty as well as multiple simultaneous incidents. In Ozbay et al. (2004), more detailed and improved probabilistic optimisation models of allocation of response vehicles for incident management are presented and a number of examples are solved for a number of probabilistic constraints.

4 Development of traffic and incident response simulation model to evaluate incident management technologies

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 (VMS), 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 RIMS software. RIMS software can be divided into three submodules:

1 traffic simulation

2 incident generation

3 incident response simulation.

Two options are provided for incident generation:

1 incident generation in accordance with estimated probability distributions

2 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.

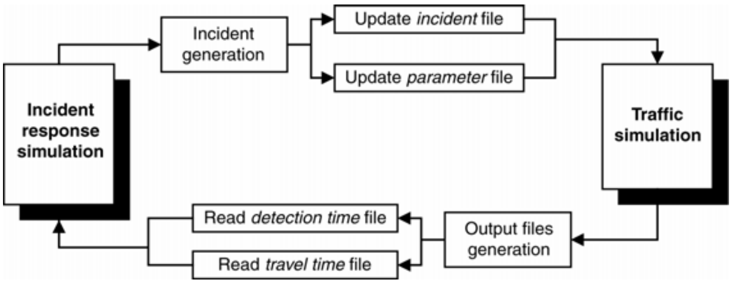
Traffic simulation is used to realistically simulate the vehicle movements given the Origin Destination (OD) demands, from which the impact of the following factors on the traffic flow could be demonstrated: number and duration of incidents and techniques employed to detect and manage these incidents. The traffic simulation model is based on the cell transmission model proposed by Daganzo (1993).

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 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, VMS, etc. Two dispatching polices are implemented in this module: First-Come-First-Served (FCFS) and Nearest Neighbour (NN) policies.

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 3.

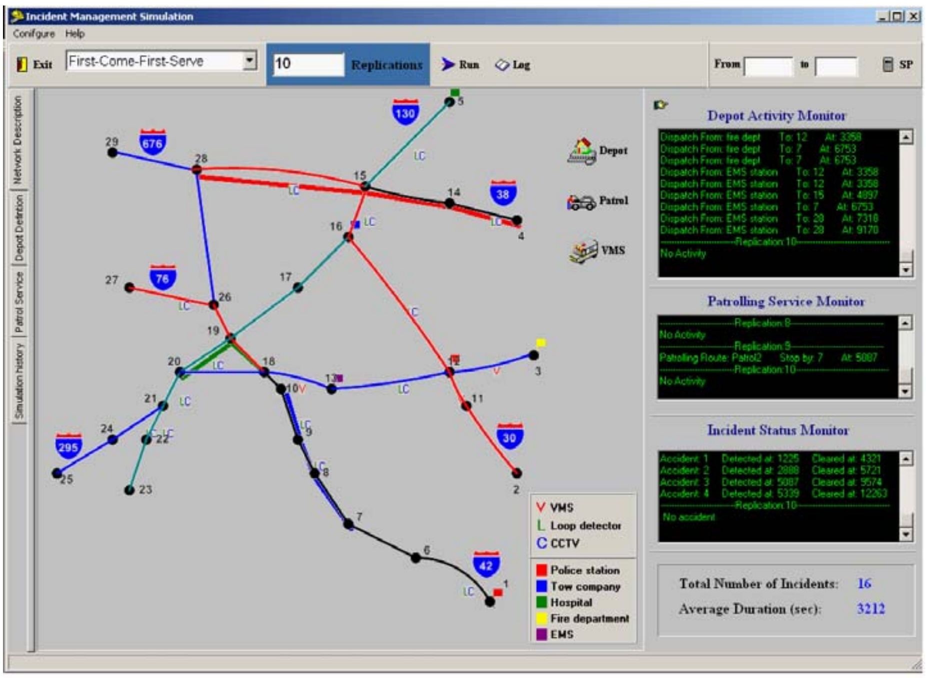
This tool program provides a friendly graphical user interface. Figure 4 is the main window of this simulation program. The middle part of the window shows the simplified representation of the South Jersey transportation network, while the three windows placed on the right-side monitor the simulation process.

Figure 3 Data flow between traffic simulation and response simulation modules



Source: Ozbay et al. (2005).

Figure 4 Main window modules



Source: Ozbay et al. (2005).

4.1 Input

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).

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 entered.

Two options are provided for the input of the average travel time for each link:

1. collecting the travel time information from the output files of the integrated traffic simulation
2. 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.

This simulation model covers nearly every type of service units used in real world applications, 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 entered in the input module. 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.

Patrol service is an important component of the whole IMS. 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.

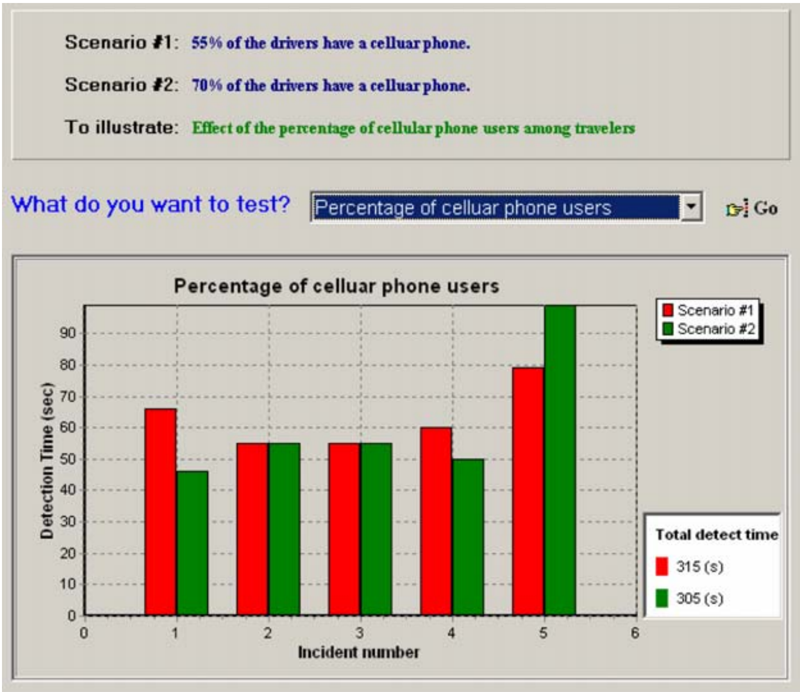
4.2 Comparison of scenarios

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:

1. Incident with diversion versus 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.
2. Effect of changing the split ratios at diversion point (user input in the parameter file) on the link travel times.
3. Effect of changing the percentage of cellular phone users among travelers on the detection time.
4. Effect of changing the threshold number of cellular phone calls received before the verification of the incident on the detection time.
5. 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 screenshot of user interface for comparing test scenarios is shown in Figure 5. The difference of the results is also numerically presented in the right bottom box.

Figure 5 Presentation of test scenarios



4.3 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.

4.4 Traffic simulation model

The developed traffic simulation model follows the hydrodynamic theory of traffic flow. It assumes that the aggregate behaviour 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* (Daganzo, 1993).

4.4.1 Cell transmission model

The cell transmission model discretises 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 travelled by a free flow moving vehicle during one simulation time interval (Daganzo, 1993).

Based on the above logic, the whole South Jersey network was modelled. 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 metreing device that released traffic at the desired rate while holding back any flow that was unable to enter the link due to capacity constraints.

4.4.2 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 is VMS.

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 southern New Jersey network. The implementation of these modules in the model is described in Ozbay et al. (2005).

4.5 Incident response module

It is important to model complex process involved in incident response after incident detection and verification. Incident response simulation is the critical component of the entire simulation system, which activates and terminates 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 (sec)

t_D: Detection time of the incident (sec)

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

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 (sec)

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

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.

Firstly, 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}.

Secondly, 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 6, ‘Incident response in patrolling service’.

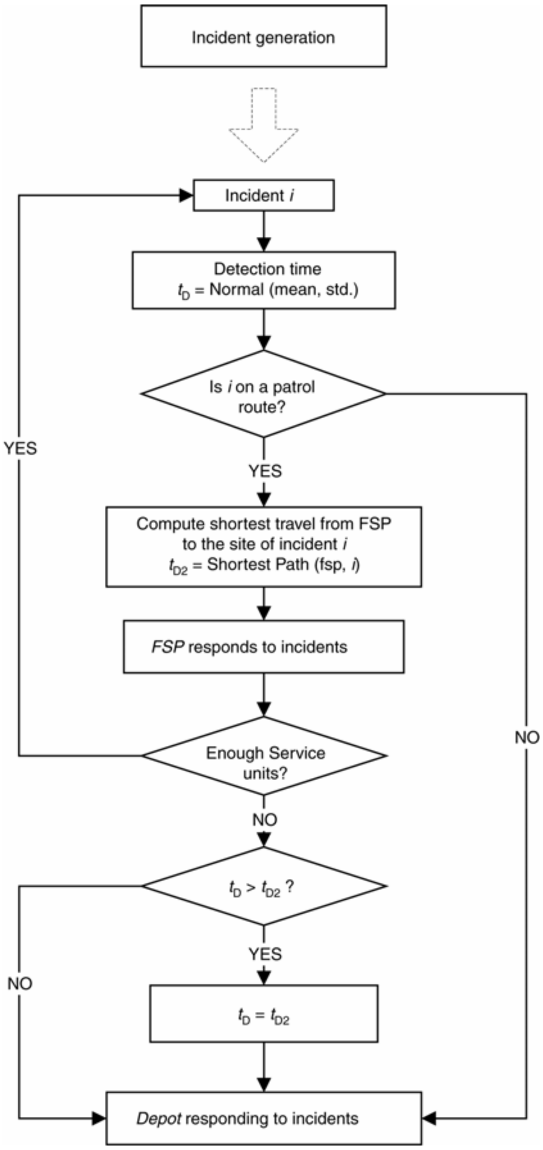
Thirdly, if there are not enough FSP service vehicles available for the specific incident, then t_D is replaced with t_{D2} and turn to the service vehicles assigned to the depot.

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 6 illustrates the steps listed above.

Figure 6 Flowchart of the incident response



4.5.1 Dispatching policy

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

4.5.2 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.

4.5.3 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:

   a. the number of the idle service vehicles at each depot

   b. 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 l, $\forall m \in \Psi$. Pick the depot, n, with shortest travel time among Ψ, that is, $m = \operatorname{argmin}\{\mathrm{dt}_m\}$.

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.

5 Evaluation of incident management strategies in study network

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

5.1 Study network

Figure 7 shows the southern New Jersey traffic network on which the developed simulation model is run, and Table 1 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.

Figure 7 Link-node representation of South Jersey traffic network

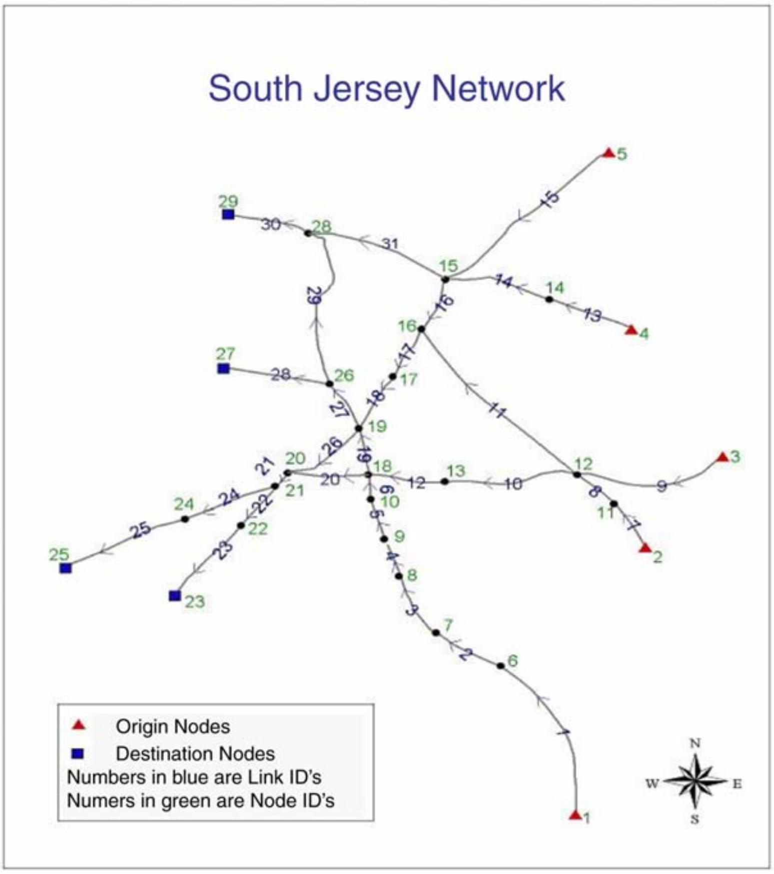


Table 1 Route description of the South Jersey traffic network

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

5.1.1 Scenario 1 – Effect of variable message signs

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 details of the incident are given in Table 2. 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.

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 GIS database of the southern New Jersey network given by NJDOT. The incident distributions are acquired from the incident databases also provided by NJDOT, and details about the distributions are discussed in Ozbay et al. (2005).

Table 2 Incident details for link 20

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

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).

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 as shown in Figure 8. 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, in Figures 8 and 9, the link density and travel time of link 20 sharply increases for a short time but soon become 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 as shown in Figure 10 and Figure 11. 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 utilised.

Figure 8 Comparison of travel times of link 20 for scenario 1

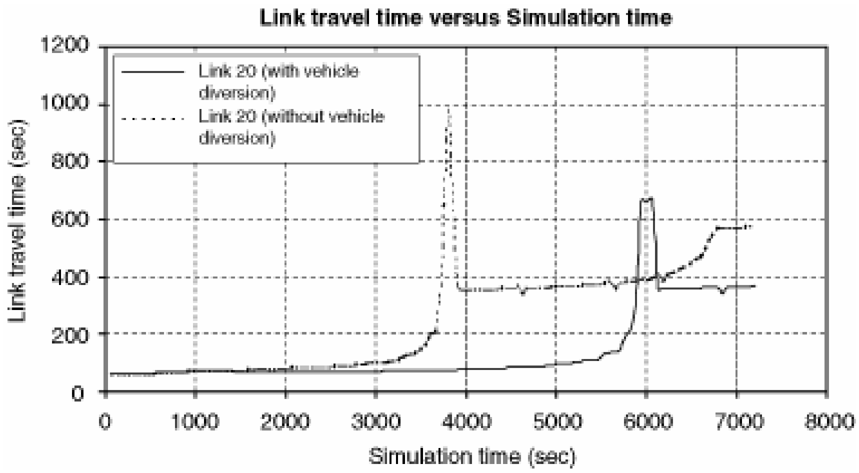


Figure 9 Comparison of vehicular link densities of link 20 for scenario 1

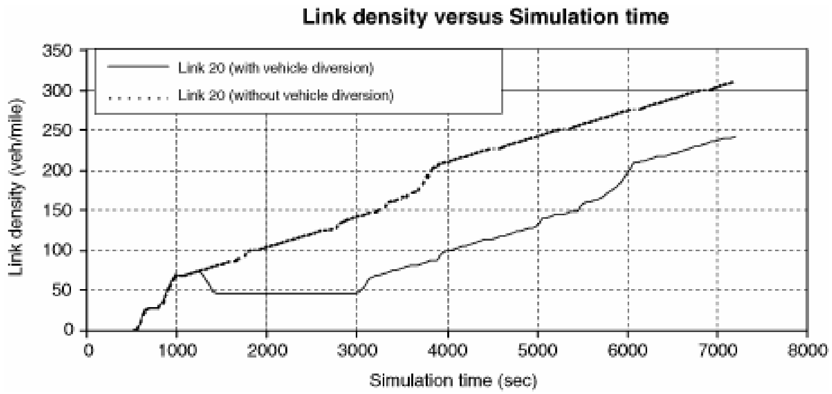


Figure 10 Comparison of travel times of link 19 for scenario1

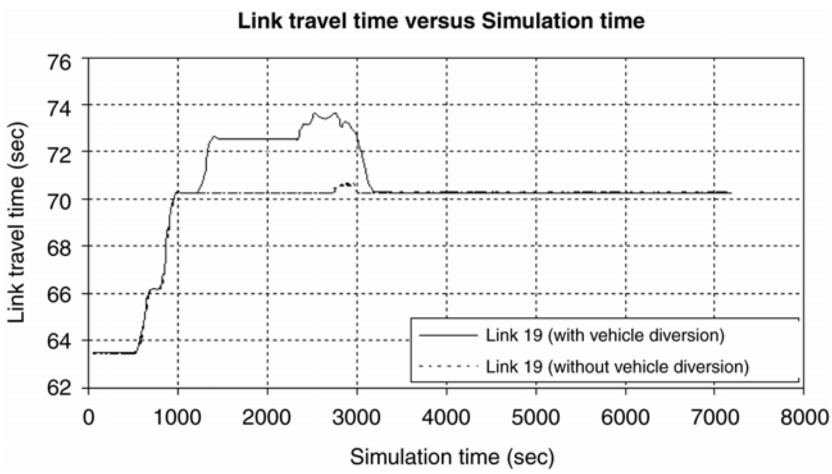
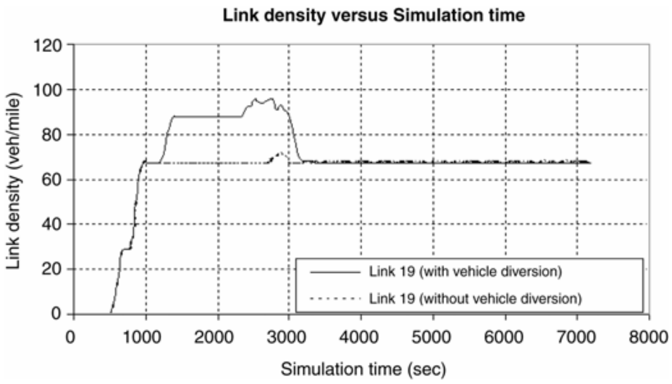


Figure 11 Comparison of vehicular link densities of link 19 for scenario 1



5.1.2 Scenario 2 – Effect of cellular phone usage

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 10 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. The results are shown in Figures 12–15.

Figure 12 Impact of % of cellular phone users on incident detection time for link 2 for scenario 2

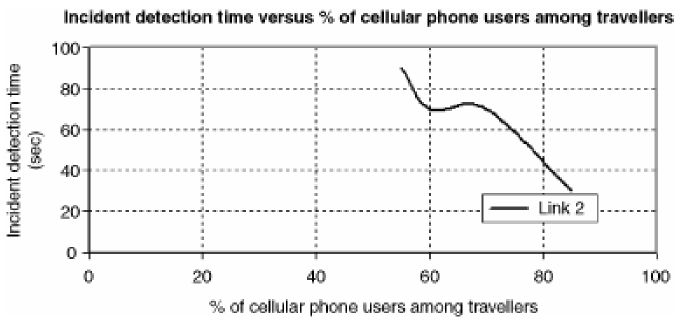


Figure 13 Impact of % of cellular phone users on incident detection time for link 17 for scenario 2

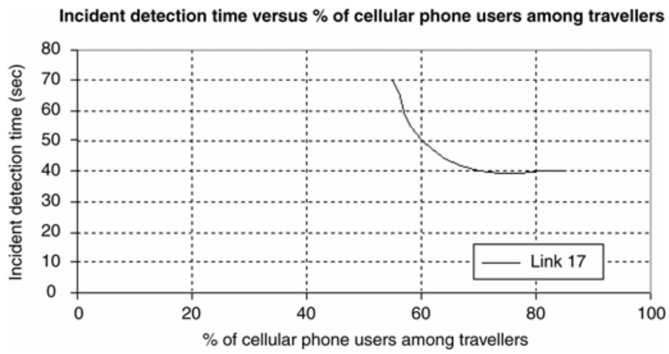


Figure 14 Impact of % of cellular phone users on incident detection time for link 11 for scenario 2

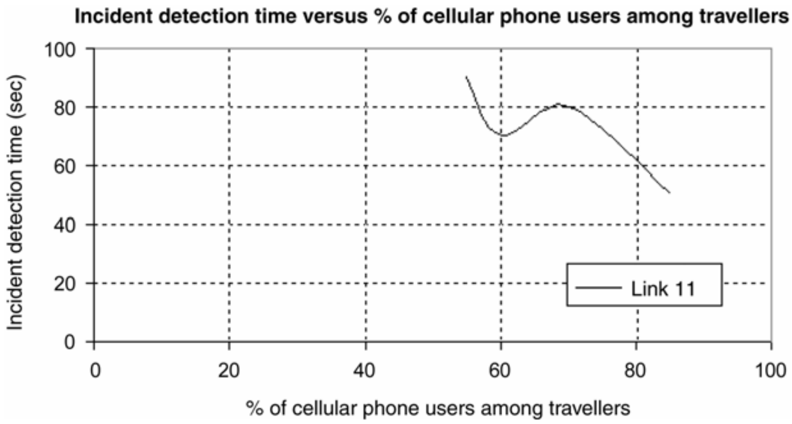
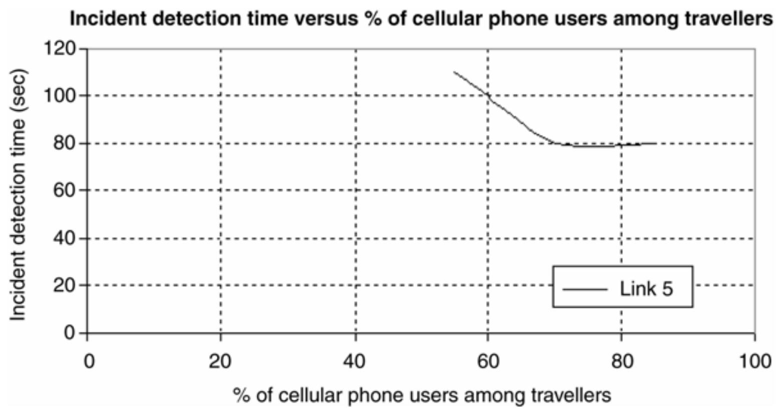


Figure 15 Impact of % of cellular phone users on incident detection time for link 5 for scenario 2



It is observed that in most cases, an increase in the percentage of cellular phone users among travellers resulted in a decrease in the incident detection time because more cellular phone users mean more cellular calls made to the Traffic Management Center (TMC), thus decreasing the time taken to detect and verify an incident. However, in few cases, such as in Figure 13 and 15, 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 travellers 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 and Upchurch (1999) 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. The next scenario investigates the effect of varying the percentage of cellular phone owners among travellers and varying the threshold number of cellular phone calls on incident detection times for various traffic demands in the southern New Jersey network obtained from the simulation model.

5.1.3 Scenario 3 – Effect of threshold number of cellular phone usage

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 (Figures 16–19).

Figure 16 Impact of threshold number of cellular phone calls on incident detection time for link 20 for scenario 3

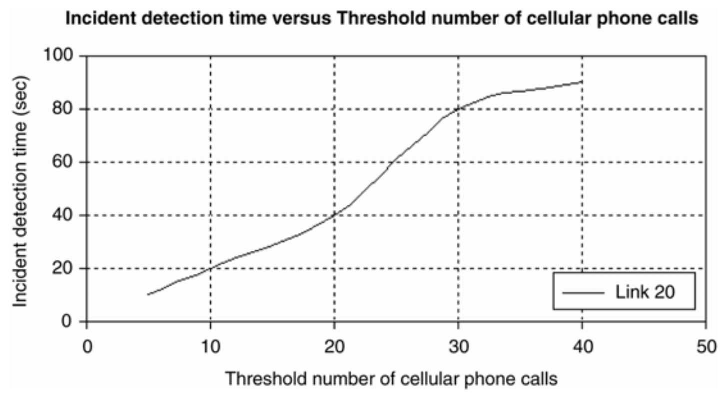


Figure 17 Impact of threshold number of cellular phone calls on incident detection time for link 17 for scenario 3

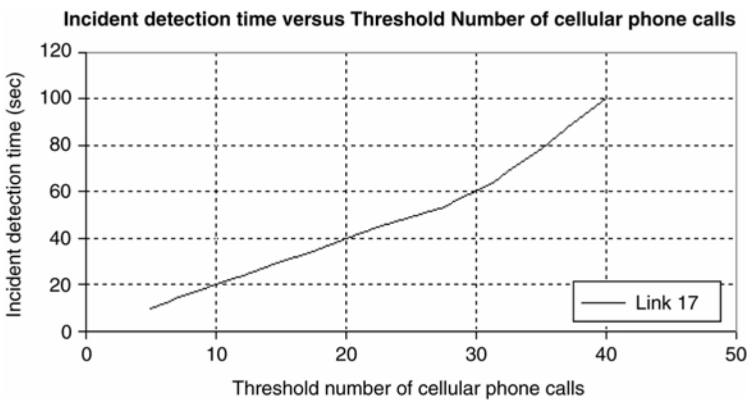


Figure 18 Impact of threshold number of cellular phone calls on incident detection time for link 11 for scenario 3

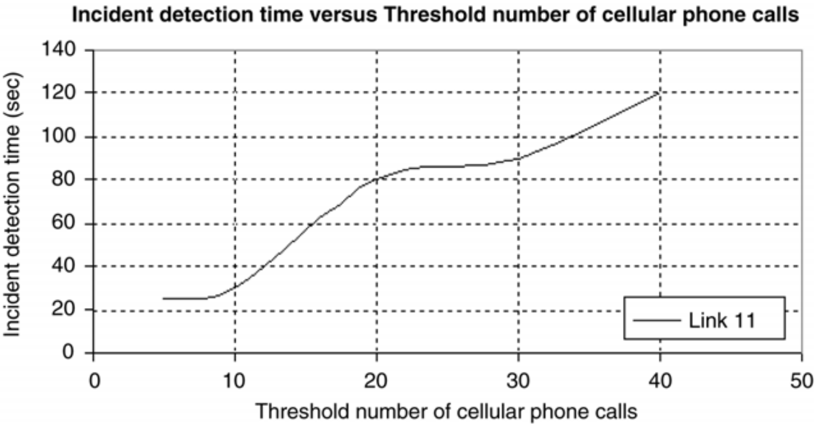
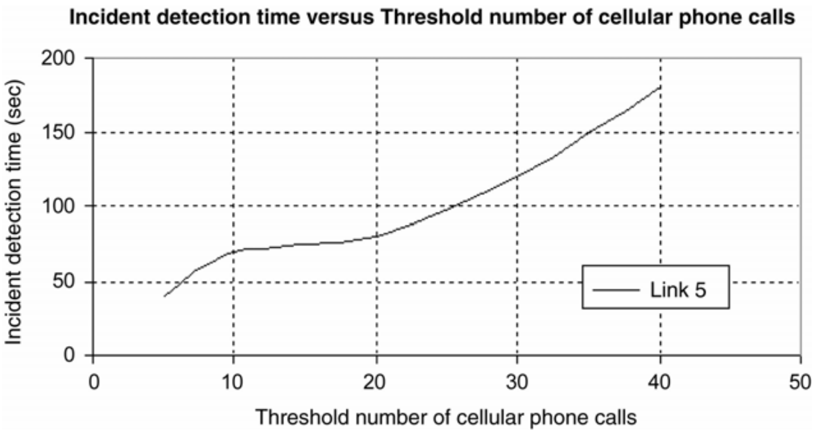


Figure 19 Impact of threshold number of cellular phone calls on incident detection time for link 5 for scenario 3



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 and Upchurch (1999). 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 modelled 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 (Tables 3–5).

Table 3 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 (sec)*
10	20	230
	40	370
40	20	70
	40	100
70	20	40
	40	80
90	20	30
	40	50

Table 4 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 (sec)*
10	20	420
	40	830
40	20	120
	40	210
70	20	90
	40	100
90	20	40
	40	80

Table 5 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 (sec)*
10	20	710
	40	960
40	20	200
	40	650
70	20	80
	40	410
90	20	70
	40	270

Table 6 illustrates the results obtained by Mussa and Upchurch (1999) 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 and Upchurch (1999) 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 6 Detection performance of a simulated cellular detection system

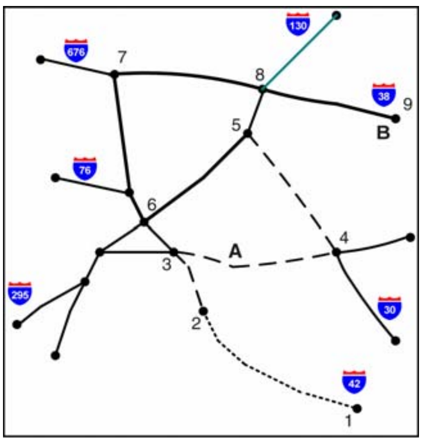
Traffic demand (Veh/hr./lane)	*Percentage of cellular phone owners*	*Probability of detection*	*Incident detection time (sec)*
700	10	90	198
1550	10	30	18
		60	36
		90	90
	90	90	12
2000	10	90	66

Source: Mussa and Upchurch (1999).

5.1.4 Scenario 4 – Effect of FSP

Consider the daily operations of the IMS implemented for the South Jersey highway network depicted in Figure 20. 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 travelling 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.

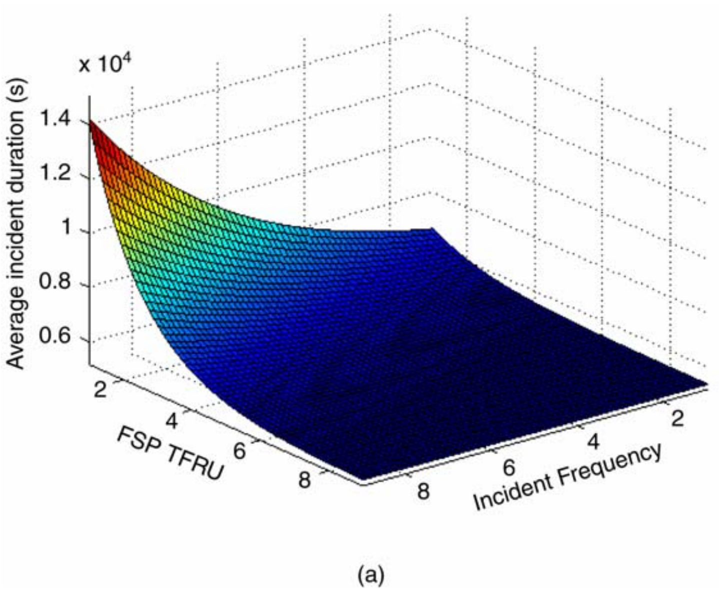
Figure 20 South Jersey roadway network

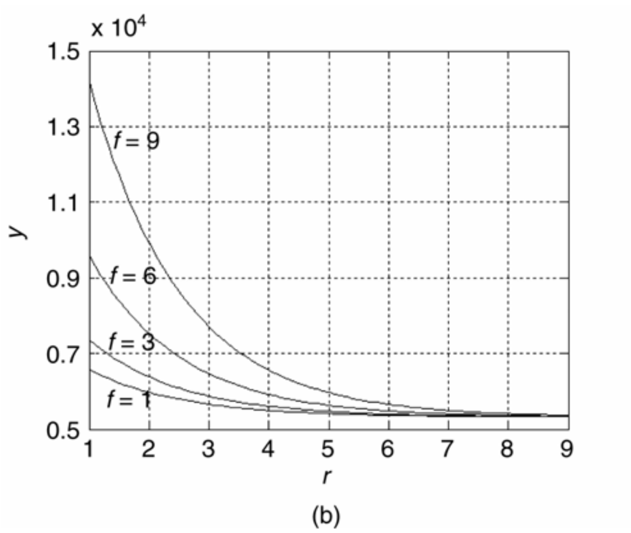


Currently, a typical patrol route in South Jersey covers all of I-76, I-676 and NJ42. To show the effect of the FSP, we change the number of Emergency Service Patrols (ESP) on this patrolling route, while keeping one available service unit at the depot and using FCFS dispatching policy only.

The response surface of service vehicles in the FSP and the incident frequency is depicted in Figure 21(a). The 2D curves for various numbers of incidents are shown in Figure 21(b). This figure shows that the average incident duration decreases significantly when the number of TFRUs used by FSP increases, especially in the cases with high incident frequency level. This shows the importance of FSP in the IMSs.

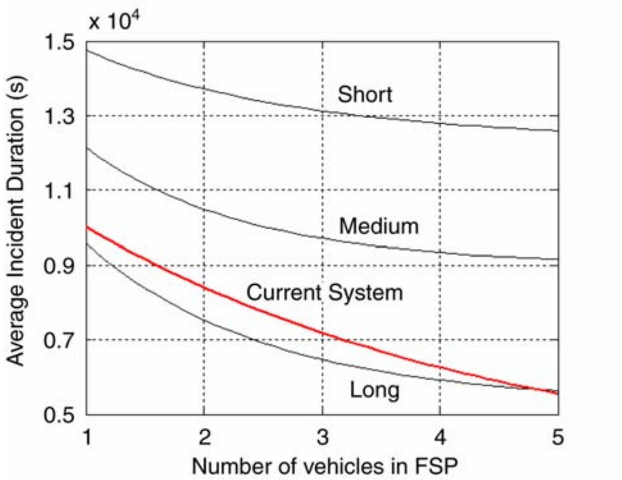
Figure 21 Response surface of FSP and incident frequency with one available unit in depot,[1] (a) response surface and (b) curves for specific *f* values





In our single patrol route case, we also check the effect of the length of the patrolling route. We compare three patrol routes, which are illustrated in Figure 20 and the realistic patrol route. The short patrol route is depicted in dotted line, from node 1 to node 2. The patrol route with 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 node 5–9. We evaluate the performance of different patrol routes under same traffic condition, $f = 6$, while keeping one available service vehicle in the depot. We increase the number of service vehicles assigned to these patrol routes from one to nine, and the curves of average incident clearance duration for each route are shown in Figure 22. It can be seen that, for the scenario considered in this study, the longer patrol route results in shorter average incident clearance duration. In addition the current typical patrol route is a reasonable choice, which is outperformed only by the longest patrol route chosen for our simulation studies.

Figure 22 The effect of patrol route length



6 Summary and discussions

In this paper RIMS software is described in detail. RIMS uses a realistic traffic simulation model based on the cell transmission model first proposed by Daganzo (1993). The developed software can also generate incidents and test various response strategies and technologies. RIMS is applied to the South Jersey highway network, evaluating 4 different incident management scenarios described in Section 5. These scenarios test the effectiveness of traffic diversion using VMS, the percentage of cell phone users and the additional service units in FSP in terms of reductions of incident durations.

The following is the summary of results with respective benefit-cost analysis. In scenario 1, the impact of route diversion using VMS on links 6 and 12, as shown in Figure 7, is analysed in terms of changes in travel times and densities on the affected links in case of an incident. The analysis of this scenario shows positive impacts of VMS deployment during an incident in terms of reductions in link travel times and link densities. The benefit-cost analysis of VMS deployment in Scenario 1 can be performed as follows. Suppose that the type of VMS suggested to be deployed is a full matrix, LED display, 3-line, walk-in VMS with a cantilever structure.

- average capital cost of deploying a VMS of the above-mentioned type on corridors is $120,000 (ITS Benefits and Unit Costs Database, 2002)
- average annual operations and maintenance cost of VMS of the above-mentioned type is $6000 (ITS Benefits and Unit Costs Database, 2002)
- average capital cost of constructing a VMS tower for the VMS of the above-mentioned type on corridors is $25,000 (ITS Benefits and Unit Costs Database, 2002)
- lifetime of a VMS of the above-mentioned type is 20 years (ITS Benefits and Unit Costs Database, 2002)
- lifetime of a VMS tower is 20 years (ITS Benefits and Unit Costs Database, 2002)

Present value of cost can be computed as $\mathrm{PVC}_k = \mathrm{TC}_k \big/ (1+i)^k$ where, PVC_k is present value of cost in year k, TC_k is total cost in year k and i is discount rate.

Assuming 5% discount rate and 20 year lifetime of VMS, the total average cost of deploying VMS on links 6 and 12 can be computed as $459,607.

Our analysis shows that total annual vehicle-hours saved (in case of an incident occurrence) by vehicle diversion due to VMS on link 6 and 12 is 39,524 vehicle-hours. Present value of total average annual benefits rendered due to VMS can be calculated as PVB = (vehicle-hours saved annually) × (monetary value of time) = $300,382. An average Value of Time (VOT) ($/hr) was employed. $7.6 per hour, which is the 40% of the average hourly wage rate in NJ, is employed as the VOT. Using this estimate of timesavings, present value of benefit for a period of 20 years with 5% discount rate is calculated as $4,245,587.

With these estimated costs and benefits, the benefit-cost ratio for deploying VMS on links 6 and 12 for a period of 20 years is obtained as 9.2. This ratio shows that there is clear benefit of using VMS during an incident on South Jersey highway network. Even with a very low VOT assumption, such as $2.0 per hour and a high interest rate such as 12%, this ratio is estimated to be 1.4 for a period of 20 years, and 1.3 for a period of 10 years.

In scenario 2, the effect of cellular phone usage on the reduction of incident detection time is evaluated. Figures 12–15 show the reduction in incident detection time on selected links with respect to the percentage of cell phone users who report the incidents in case of an incident at these links. In scenario 2, the effect of the number of calls made to TMC is evaluated. It is observed that increasing the threshold number of cellular phone calls caused an increase in the incident detection time due the fact that TMC has to wait for a longer time before the incident is assumed as verified and a response unit is dispatched.

Clearly, there are no costs of cellular phone usage to TMC. Therefore, a benefit cost analysis is redundant for these scenarios.

In scenario 4, we investigate the effect of the FSP on incident durations. In Figure 21, the reduction in incident duration is shown with respect to number of service units in

FSP for various values of incident occurrence rates. For the lowest incident occurrence rate, $f = 1$, we can observe a reduction of approximately 500 sec (8.3 min) in incident duration due to an increase from 1 to 2 service units. According to a report by the ITE Journal (Institute of Transportation Engineers, 1997), each minute of incident duration results in 4–5 min of additional delay. Thus, travel time saved by FSP would be approximately 2000 sec.

Let us assume that a minimum number of 200 vehicles benefit from the reduction of incident duration. Then, for each incident we would expect 200 × 2000 sec (111 vehicle-hours) of travel timesavings. The South Jersey incident database shows an average of 800 emergency incidents per year in the study corridor. Therefore, an annual estimate of travel timesavings during incidents due to the increase in FSP service units can be estimated as 88,800 (111 × 800) vehicle-hours. Assuming the VOT as $7.6 per hour as before, the estimated annual benefit of adding one more FSP service unit to the fleet is $674,880.

The cost of a FSP service unit includes operational costs including hourly costs, communication costs, administrative costs and capital costs. Skabardonis et al. (1998) shows a detailed description of each cost category of FSP costs estimated by the Los Angeles County Metropolitan Transportation Authority (MTA). An estimated cost of one FSP service unit is given as $110,480 in 1997 dollars. Assuming a 5% discount rate, we can convert this cost to 2006 dollars as $171,394 per service unit.

To that end, an estimate of benefit-cost ratio of an additional service unit in FSP under the lowest incident occurrence rate ($f = 1$) can be given as 674,880/171,394 = 3.94. This value is in accordance with the estimates given in the literature. For example, Fenno and Ogden (1998) list the benefit cost ratios of FSP deployments reported in various studies conducted in 1990s. In these studies, the estimates for the benefit cost ratio varies from as low as 2.0 to as high as 36.2. In a more recent study, Levinson and Parthasarathi (2001) reported a benefit cost ratio of 5.9 in the Los Angeles area.

The developed simulation model, RIMS, can also be used with other traffic networks. Future work can involve analysing the benefit cost ratios of other incident management technologies deployed in larger and more complex transportation networks.

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Note

[1]y denotes the response variable, the average incident duration in sec. f denotes the average number of incidents that might occur over the roadway network during a given time period. r denotes the number of service vehicles in the FSP.