INCIDENT MANAGEMENT SIMULATION

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Abstract

A simulation model is developed to evaluate the performance of incident management operations. Washington D. C. beltway network is used as the study highway. Beltway network is selected due to the availability of real-world incident data collected as a part of another study (Ozbay et al., 1997). Five incident types are considered. Their severity degrees are assumed to be related to the incident characteristics, such as number of vehicles involved, number of injuries, etc. A relationship between the severity degree and the allocation of necessary emergency units is derived from previous data found in the related studies (Dhingra, 1996, Kachroo et al., 1997). The same data source is used to estimate incident clearance times. There are three different periods of time that can be minimized during an incident removal process: *Detection and verification time*, *response time* and *clearance time*. This study focuses on the variation of detection and response times for various deployment strategies of Emergency Response Teams (ERT). *Arena* simulation package is used to model and examine the effects of various incident management strategies. An example scenario is given and the possible strategies are compared based on the statistical values obtained from the simulation output analysis.

Keywords: Incident management; Simulation; Arena; Siman
Topic Area: C7 Traffic Simulation Models

1. Introduction

Due to the enormous increase in motor vehicle usage over the last 50 years, highway congestion has become a severe problem in the US. As the problem revealed itself in terms of monetary units in highway transportation costs; during the last two decades, an increased awareness to reduce congestion has emerged on the government's part. Under the stipulations of the Transportation Equity Act-21 (TEA-21) agreement in 1998, there has been more rigorous attempt to understand the causes of congestion, and to find better ways to alleviate it rather than building new roads.

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 minimized 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-organized 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*.

i. 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, 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.

ii. 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.

In this study, we attempt to evaluate the effectiveness of different network related incident management strategies in terms of vehicle delays. Washington, D. C. beltway is chosen as a study network for this task. The network is modeled and evaluated in *Siman*[1] simulation language.

The outline of the paper is as follows: Section 2 reviews some of the relevant studies, and also gives an introduction to the problem definition. Section 3 presents the problem definition along with the explanation of some basic terms in incident management. Section 4 introduces our simulation methodology. Section 5 describes the application of our simulation model in an example incident management scenario. Finally, section 6 presents the conclusions and the shortcomings of the analysis.

2. Previous work

Incident management studies can be classified under 2 categories:

i. General studies that try to understand the reasons, durations and occurrence rate of incidents (Ozbay and Kachroo, 1999, Ozbay et al., 1997, Sullivan, 1997);

ii. Evaluation studies aimed at determining best incident management strategies under certain conditions (Zografos et al., 1993, 1994).

Incident durations heavily depend on the number of vehicles involved, lanes blocked, injuries and fatalities, the involvement of a truck, incident location and traffic volume. In a recent study, Ozbay et al. (1997), data is collected in the Washington, D. C. / Northern Virginia area to study the effects of these factors on incident durations. Also, in this study, resource requirements for an incident based on incident type and certain incident attributes are determined by the data collected.

Sullivan (1997) presents the estimation results of number of incidents and the associated delays, which depend on road characteristics, traffic volumes and incident management. A computer model called *Impact* is utilized for this purpose. In Sullivan (1997), incidents are categorized into seven standard types: Abandoned vehicles, accidents and fires, debris on highway, system failures, stalled vehicles and tire problems.

In the second category of incident management studies, Zografos et al. (1993) contains a methodological framework proposed to reduce the incident duration by an optimal deployment of emergency units. In order to optimize the number of emergency vehicles and their jurisdiction areas, *Kronos* simulation program is used.

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[1] Siman language is embedded in Arena Simulation software

In Zografos et al. (1993), freeway incident management activities are grouped into three major categories:

(i) *Incident Detection*, (ii) *Motorist Information*, (iii) *Incident Remedy*

Zografos et al. (1993) have shown that the delay caused by incidents depend on

i. The traffic flow at the time of incident,
ii. Remaining capacity of the particular freeway section after the incident occurs,
iii. Total incident duration and queue dissipation rate after the incident is cleared.

Three steps are proposed to simulate the traffic flow restoration problem in Zografos et al. (1993). First step generates incidents from a given arrival distribution. Incidents are generated with two properties: *incident type* and *incident location*. Second step selects the suitable ERT (emergency response team) to be assigned. This selection process is based on matching the incident location with ERT staging areas. ERT only responds the incidents that occur in their response areas. Finally, step three is the operation of ERT based on predetermined dispatching policies. *2* dispatching policies are tested, namely, first-in-first-out and nearest location.

Another study by Zografos et al. (1994), deals with utilization of simulation to evaluate the performances of several incident management scenarios. Basically the study is solely focused on minimizing the response time of emergency units.

3. Background information & problem definition

Incident management consists of several actions. These are time-related steps between the incident occurrence and the time that the traffic flow resumes to normal. These steps are shown in Figure 1.

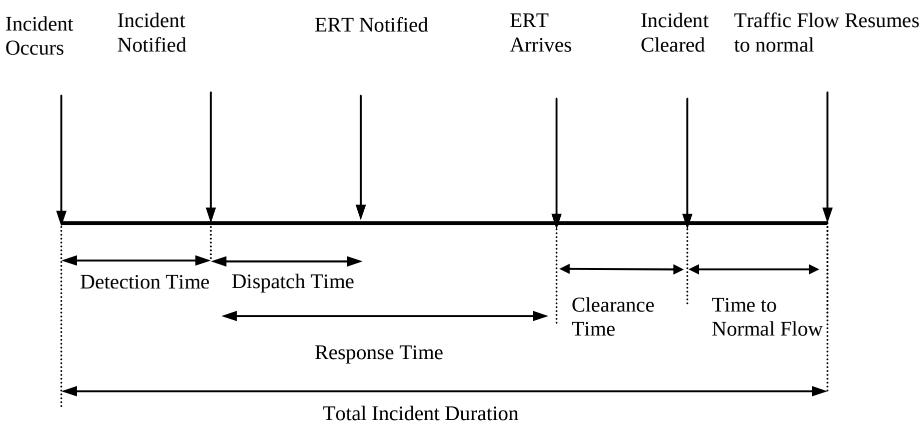


Figure 1 Time Line of an Incident Duration (Zografos et al., 1994)

<u>Detection Time</u>: This is the time measured from the incident occurrence to the time that the related agencies are informed about the incident. These agencies are state police, highway and freeway safety patrols, department of transportation, or aerial crew (Ozbay and Kachroo, 1999)

An incident can also be detected by commuters, using roadside call boxes or cellular phones, or by closed-circuit television cameras that are installed at different locations on the network.

Response Time: Once the incident is detected, it should be verified by the police officer or by the freeway service patrol. Depending on the type and the severity of the incident, related agencies are informed. This period is called *dispatch time*. Here, the police officer or the freeway service patrol is responsible to assess the incident and decide whether there is need to divert the traffic or not.

In case of multiple incidents occurring at the same time period, there are three dispatching policies. These are: first-in-first-out (FIFO), nearest territory and the highest priority (based on incident severity). Hence, response time is also dependent on the dispatching policy of the incident management center. Response time also includes the travel time of emergency response team (ERT) to arrive at the scene. Thus, the duration of ERT response depends on the experience of the police officer in handling an incident and the availability and closeness of the required ERT.

Clearance Time: This is the time between the arrival of the response team and the time when incident is fully cleared (all traffic lanes are open).

Time to Normal Flow: This is the time required for the traffic to reach its normal flow after the completion of the incident clearance.

This paper focuses on detection time and response time.

Figure 2 depicts the change in the traffic flow due to an incident. This diagram is based on the deterministic queuing theory. The horizontal axis represents time and the vertical axis represents cumulative traffic volume arriving to the point where the accident occurred. The slope of the line AC is the initial traffic flow rate (arrival of traffic). When an incident occurs, the actual flow rate past the incident is reduced due to the reduction in the capacity of the freeway at this point. The slope of line AB represents the flow rate past the incident. When the incident is fully cleared, the flow rate increase until it becomes equal to the maximum flow rate, the slope of BC. This is also equal to the slope of KK (See below explanation). When all the delayed traffic passes the incident location, the traffic flow returns to its normal rate (slope of AC).

[In the absence of congestion all arriving cars are served because the line KK, which represents the cumulative capacity (maximum departure rate) has a steeper slope than the arrival rate of traffic. At B, when all the lanes are cleared, traffic starts departing at capacity, thus the cumulative departure rate becomes equal to the max cumulative departure rate until the queue is cleared up at point C. Then, the arrival rate becomes less than the max departure rate]

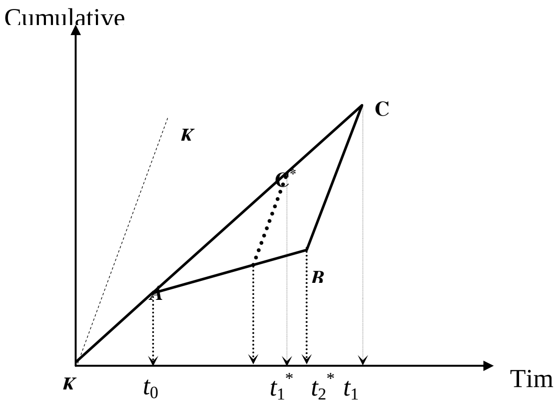


Figure 2 Total Delay due to an incident occurrence (Morales, 1987)

It is clear that if the number of response units is increased, incident durations will be minimized. The decrease in incident removal time t_1 to t_1^* as shown in Figure 2 results in t_2 shifting to t_2^*. This leads to decreased user costs and user discomfort and less air pollution (B^*BCC^* in Figure 2). However, in real life applications, as budgetary concerns set an upper bound constraint, the fleet size is always limited (Zografos et al., 1993).

Thus, the overall goal of any incident management strategy is to minimize the total traffic delay due to incidents. This problem can be formulated in a very simple way as follows:

$$\textbf{Minimize} \quad \sum_{i=1}^{365} TD_i$$

$$\textbf{Subject to} \quad \sum_{j=1}^{k} N_{ERT\,j} . C_{ERT\,j} \leq B$$

Where,
TD_i= Total Daily Delay
N_{ERTj}= Number of Emergency Response Team (ERT)
C_{ERTj}= Cost of ERT vehicle
B= Total Budget
k=Number of emergency vehicle types

However, it is not possible to express total delay (*TD*) in a closed form equation, thus we propose the use of simulation as a way to evaluate *TD* given the network properties, dispatch policy and budget constraints.

Thus, the aim of incident management operations is, depending on the prevalent dispatching policy, to come up with an efficient deployment strategy to achieve the minimal possible incident duration, while the fleet size constraint is satisfied.

4. Simulation methodology

As an objective function evaluator for the minimization problem shown above, a simulation program developed in *Siman* is used. This simulation program is mainly used to determine the total delays due to incidents and to evaluate various incident response strategies under different dispatching policies.

For simulation purposes, incidents are classified according to their types. In order to start the simulation process and to determine which ERT has to be assigned to clear the incident, incident type should be known. For instance, there is no need to send an ambulance or a fire truck to a disablement incident caused by a mechanical problem. Each incident type has its own equipment and personnel requirements. We assume five incident types:

i. Property damage
ii. Personal injury
iii. Disabled truck
iv. Vehicle fire
v. Cargo spill

According to the classification given by Sullivan (1997), property damage, personal injury and vehicle fire incidents are under the “accidents” category. Disabled truck comprises the categories “mechanical” and “stalled”. Abandoned, flat tire and other categories presented in Sullivan (1997) are not included because the Northern Virginia original data set (used in Ozbay and Kachroo, 1999) excluded the disablement accidents due to the overwhelming number of such incidents. These accidents do not cause major traffic disruptions since they are cleared very quickly by the owners of these vehicles, most of the time without the help of Incident management crews.

In Ozbay and Kachroo (1999), incident data collected in the Northern Virginia area is presented (Table 1). There are no fatality accidents recorded in this data set that was collected for more than 6 months in 1996. There were also very few HAZMAT (hazardous material) accidents during the same time period.

Table 1 Average clearance time (minutes) by incident type (Ozbay and Kachroo, 1999)

Inci	**Ro**	**Pro**	**Pers**	**Disa**	**Veh**	**HAZ**	**Wea**	**Disa**	**A**
Mea	26.	42.6	50.81	60.2	42.5	244.0	82.5	27.1	4
# of	9	401	173	14	7	3	2	41	6

Due to the very low number of fatality accidents with respect to total number of traffic accidents, we decided not to include fatality accidents in our study. In fact, according to the Cambridge Systematics study, most of delays are caused by less severe accidents that occur more frequently (Cambridge Systematics, 1990). This is why, incident management strategies are developed to address these less severe but more frequent accidents.

Next, we describe the steps of our incident management simulation methodology shown in Figure 3.

4.1 Steps of the simulation logic

Step1: Incident Generation (t_0)

Incidents can be generated at any arbitrary location on the highway network like in real world. Each generated incident is assigned to one of the *5* incident types mentioned above. It is clear that, each incident type has its specific characteristics, such as number of vehicles involved, number injuries, etc. (Henceforth, these characteristics will be named as *Incident Response Measures*, since they are utilized as measures in ERT allocation process (See Table 2)). Therefore every incident is assigned an *Incident Response Measure* (i.e. if the incident is *personal damage*, then *CI* variable gets an integer value from a probability distribution function). Incident type and incident response measures are determined by discrete probability distributions developed based on the data given in Table 4.

Table 2 Incident Response Measures

Incident Type	**Incident Response Measures**
Personal Damage	Number of Vehicles Involved (*CI*)
Personal Injuries	Number of Injuries (*I*)
Disabled Truck	Number of Trucks Involved (*TI*)
Vehicle Fire	Number of Vehicles Involved (*CI*)
Cargo Spill	Number of Vehicles Involved (*CI*)

It should be noted that the model generates incident with equal probabilities at each link in the network. It is clear that incident occurrence at any link is directly related to roadway characteristics and traffic flow; hence some highway sections will have higher incident occurrence rates. However, it is not easy to incorporate this fact in the model due to lack of data. All the highways included in our study network are freeways and their designs and flow do not differ drastically from each other. Therefore, all links in the network are assumed to have the same probability of incident occurrence. [2]

Step 2: Incident Detection & Verification ($t_0 + t_1$)

Incident detection / verification time is measured from the moment that an incident occurs until the time it has been verified by the response team.

In this paper, we assume that if the patrolling units fail to detect the incident, it would take maximum *20* minutes for the responsible agencies to be informed by other means (cell phones, surveillance cameras, etc.) and verify the incident at its location. This assumption is also in agreement with some of the recent studies that collected detection and verification time data. For example, in a recent study conducted at UC Berkeley to evaluate the effectiveness of an existing incident management program in California using field data, average incident detection and verification time is found to be around *14.1* minutes for all the accidents observed during the study. (Skabardonis et al., 1998). In Washington State, the detection and verification times were slightly lower, *21.2* minutes during 1994-1995 (Nam and Mannering, 2000). However, this also agrees with our assumption of a maximum *20* minutes for detection and verification times.

In another study by Stamatiadis et al. (1998), researchers evaluated the existing incident management program titled Massachussetts Motorist Assistance Program (MAP). In this study, the researchers found out that incident detection / response time was on the average *10* minutes for situations where MAP exists and it was *25* minutes for cases where MAP did not exists.

The detection and verification time, t_1, is added to the recorded incident occurrence time in order to check whether the incident takes place during the rush hour or not. (Since the travel time increases during rush hours, the speed of ERT vehicles should be adjusted accordingly (See *Step 3*)).

In our simulation model, the verification process utilizes *3* attributes of an incident: *Incident location*, *incident type* and *incident response measures*. These *3* attributes are used by the patrolling unit in determining the necessary ERT and their numbers. Verification process progresses as follows: After determining the incident type, required ERT is identified. The relationship between incident types and required ERT is shown in Table 3. Also, the quantity of ERT is determined by using incident response measures. The relationship between incident response measures and required number of ERT given in Table 4 is based on the data collected and analyzed by Ozbay et al. (1997) and Ozbay and Kachroo (1999). Finally, based on the incident location, the closest ERT unit is assigned for the incident.

Table 3 Required Emergency Units for Incident Types (Ozbay et al., 1997, Ozbay and Kachroo, 1999)

No	**Incident Type**	**Related Response Units**			
		Tow	**Fire**	**Ambulan**	**Clean**
1	Property	X	X	X	-
2	Personal Injury	X	X	X	-
3	Disabled Truck	X	-	-	-
4	Vehicle Fire	X	X	X	-
5	Cargo Spill	X	X	X	X

[2] It should also be mentioned that, although the possibility of multiple incidents is very small in real life, our model takes this probability into account by allowing a variance in incident occurrence distribution function.

Table 4 Incident Response Requirements (Based on the data given in Ozbay et al., 1997, Ozbay and Kachroo, 1999

	Incident Type	Occur. Rates	Measure	Range	Probability	Resource Allocation
1	**Property Damage**	61.43 %	No. of Cars Involved	1	0.186	1 Tow-Truck
				2	0.7	2 Tow-Trucks
				3	0.114	3 Tow-Trucks
						* When Range=2 or 3, always send 1 Ambulance
						* When Range=3, always send Fire Engine
2	**Personal Injury**	35 %	No. of Injuries (NI)	1	0.73	1 Ambulance
				2	0.16	2 Ambulances
				3	0.06	2 Ambulances
				4	0.05	3 Ambulances
			No. of Cars Involved	2	When NI=1,2,3	2 Tow-Trucks
				3	Only When NI=4	3 Tow Trucks
3	**Disabled Truck**	1.96 %	No. of Truck Involved	1	0.98	1 Tow Truck
				2	0.02	1 Tow Truck
4	**Vehicle Fire**	0.98 %	No. of Cars Involved	1	0.8	1 Fire Engine
				2	0.2	2 Fire Engines
						* Always send 1 Tow Truck
						When Range=2, send 1 Ambulance
5	**Cargo Spill**	0.63 %	No. of Cars Involved	0	0.25	
				1	0.75	1 Tow-Truck
			No. of Truck Involved	1	0.95	1 Tow-Truck
				2	0.05	2 Tow-Trucks
						* Always send 2 Ambulances
						Always send 2 Fire Engines
						Always send 1 Cleanup

Step 3: ERT Arrival ($t_0 + t_1 + t_d$)

Each ERT depot has a predetermined location in the network setting and they have a certain number of emergency equipment. If the required number of ERT is not available in the selected depot, then the second closest one is searched for the missing emergency unit. For instance, if the incident requires two ambulances and one tow-truck and there is only one ambulance available in the closest ERT depot, then another ambulance is requested from the second closest depot. It is apparent that in this case response time will be increased due to the longer distance. The recorded time ($t_0 + t_1$) in *step 2* is used to adjust the speed of the selected ERT. After obtaining several arrival times for each emergency unit, the highest one is used in the response time for statistics (Here, it is assumed that the response time of incident is recorded when the last ERT unit arrives at the incident location).

Step 4: Incident Clearance ($t_0 + t_1 + t_d + t_c$)

We use the results given in Ozbay and Kachroo (1999) for incident clearance times. Table 1 shows the mean values of the available data for incident clearance durations for various incident types. After determining the corresponding clearance time, it is added to the time obtained in *step 3*.

4.2 Development of discrete-event simulation model using Siman

Siman simulation language enables us to simulate incident clearance with its network capabilities. However, *Siman* utilizes networks to simulate manufacturing where materials are conveyed to *fixed* locations. The available network features in *Siman* are considerably limited to create and simulate a highway network. Although several modifications are done in the modeling, every step of an incident clearance process mentioned in Section 4.1 is perfectly modeled in *Siman*. The model used here includes the speed change on the incident link and links upstream caused by the bottleneck effect of the incident.

5. Case study

In this section we describe the application of our simulation model using an example decision-making scenario undertaken by Incident Management Center of Washington, D.C. beltway network located at Arlington, Virginia (Figure 4). We utilize our model to assess the effectiveness of the possible strategies in this example scenario.

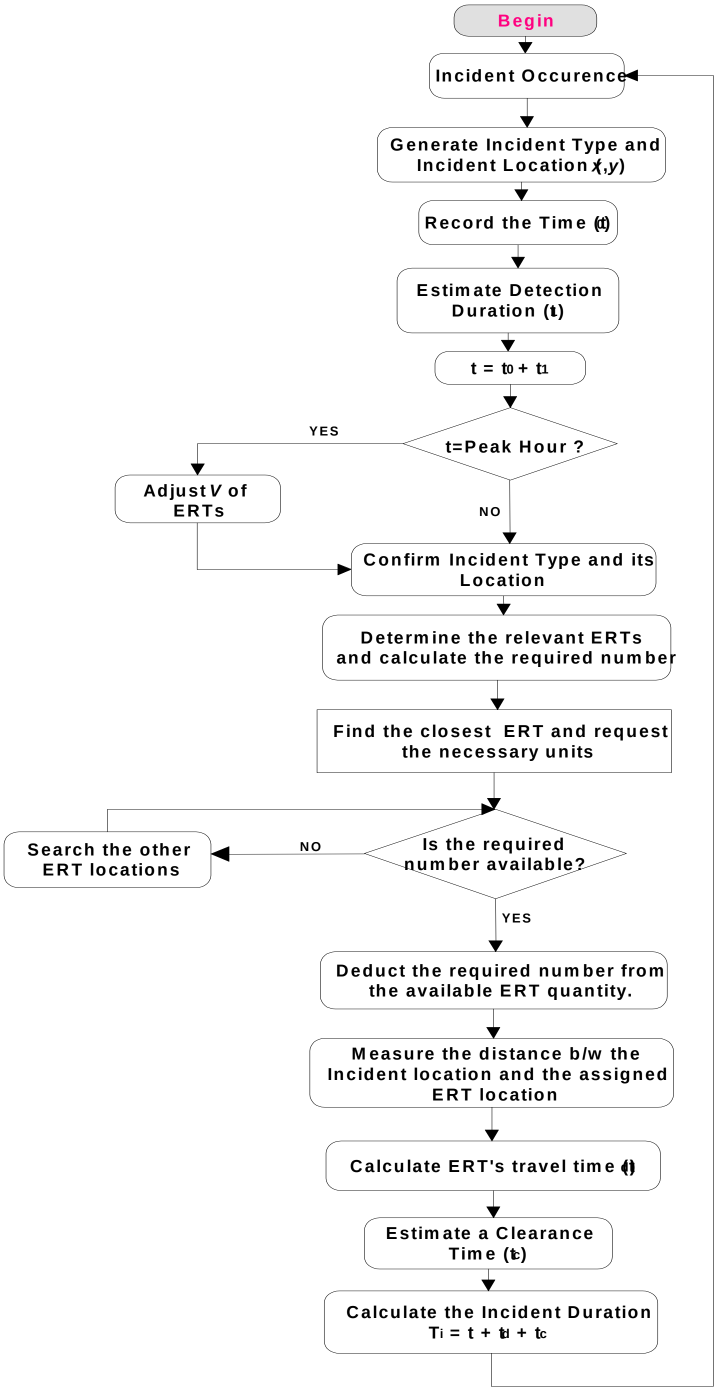
Example Scenario

Suppose that the Incident Management Center considers purchasing an additional ERT unit. However, first they want their current ERT deployment strategies to be evaluated considering the network properties and the available resources, and then invest on the most necessary unit. In other words, they want to identify the best choice of an additional unit in terms of reduced incident delay.

The outline of our analysis is as follows:

i. First, given the network properties and the available resources, we will analyze the effectiveness of the current setup with the prevalent dispatching policy. Here, we make several assumptions on the number of ERT units, their locations and network properties. These assumptions are listed below. Based on these assumptions, the network will be simulated for one year, and the performance of the current ERT deployment strategy will be identified based on the following statistics: (i) Average incident duration, (ii) Average detection time, (iii) Detection technique (patrolling units or other available means), (iv) Utilizations of the ERT, (v) The average number of calls in the emergency vehicle request lines.

ii. Second step is to determine the additional unit to be introduced. Here, the major problem is the difference between the work routines of ERT. Emergency vehicles, such as ambulances, tow-trucks and fire trucks, are utilized on-a-need basis. The most necessary emergency vehicle can be determined from the utilization statistics. For example, if the utilization of the ambulances is considerably higher, it means that an additional ambulance is needed. However, this type of statistics is not useful for measuring the need for patrolling units. Patrolling units are utilized repeatedly, since they continuously travel on their predetermined routes. Their effectiveness appears in the detection time reductions.



t: Time
V: Speed

Figure 3 Flowchart of the simulation methodology

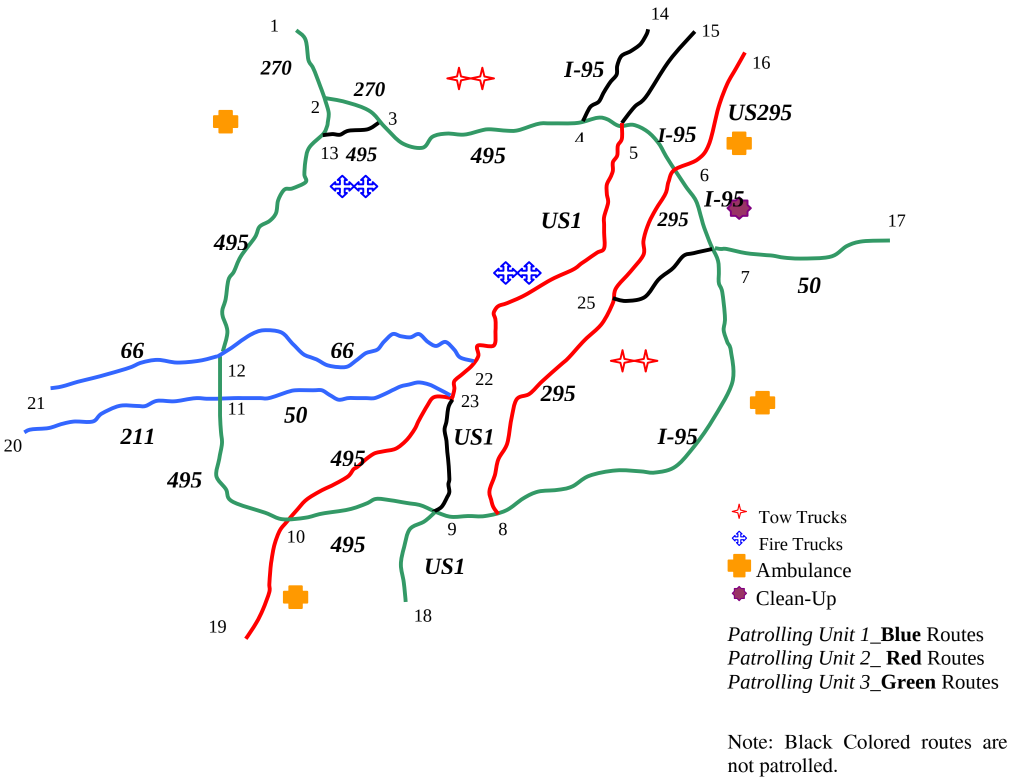


Figure 4 Washington, D.C beltway network and the current ERT setup

Hence, the problem is to make a selection decision between an emergency vehicle and a patrolling unit. This decision-making will be solved by two sets of analysis. First, we will determine the most necessary emergency vehicle using the utilization statistics obtained in the first step of our analysis. Then we will increase its number by one while keeping the same number of patrolling units. We will simulate the new ERT setup with several different locations for the additional emergency vehicle for one year, observe the incident delay reductions and determine the optimal location for the new unit. Second, we will increase the number of patrolling units by one, while keeping the same number of emergency vehicles. We will simulate the new setup with several different routes for the new patrolling unit for one year, and observe the incident delay reductions. Finally, based on the reductions in incident durations obtained from both cases, the most effective additional unit will be determined.

Assumptions

i. It is assumed that for the highway network shown in Figure 4, Washington, D.C. beltway incident management center owns *3* freeway patrol units, and has access to *4* fire trucks, *4* ambulances and *1* cleanup service truck in the vicinity of the network.

ii. The current locations of the ERT units, and the routes of the freeway patrol units are shown in Figure 4. The total length of the patrolling unit route covers *89%* of the total network length. The locations of ERT units and the patrolling routes are randomly selected without any optimality concern, because in real-life, their locations represent local fire departments and hospitals within the area and they are not necessarily at optimal locations.

iii. It is assumed the current incident occurrence has a lognormal distribution with a mean of *85* and a variance of *25* minutes. Also, in the simulation, we use the data given in Table 4 for estimations of incident types and incident response measures (Ozbay et al., 1997, Ozbay and Kachroo, 1999).

iv. In order to calculate *the length of the jam queue*, we assume that each highway in our study network consist of *4-lanes* and has *2000 veh/hr/lane* peak, *1100 veh/hr/lane* off-peak hour demands and a roadway capacity of *2490 veh/hr/lane*. (The capacity is taken from a speed-flow relationship as given in Small (1992) which was developed by Boardman and Lave (1977) for Washington, D.C beltway. Usually the capacity per lane for most of the highways is *2000 veh/hr/lane*). This assumption is required to reduce the speed of ERTs in the network due to congestion.

v. Also, it is assumed that the center currently prevails a FIFO dispatching policy.

Based on the assumptions given above, we simulate the current network for one year. The results are presented in Table 5 and Figures 5, 6 and 7[3]. According to our analysis, the current ERT setup can only handle the incidents up to an occurrence rate with a mean of *54* min and a variation of *25* minutes (incident occurrence rate: time period (min) for one incident to take place), resulting an average incident duration of *113.07* minutes (Figure 5). Beyond this point, the available resources become insufficient to remove the incidents for the entire year, and the delay approaches to infinity. Henceforth, we refer this point as the "terminal point on x-axis" Also, it is seen that the incident duration is asymptotic to *80* minutes, which implies the minimum incident time with the available resources. We refer to this point as the "terminal point on y-axis." Our results in Figure 5 also agree with real world data presented in Ozbay and Kachroo (1999) and other studies. It is clear that the incident duration will increase as the incident occurrence rate increases.

It is clear from Figure 6 that tow-trucks are the most utilized emergency vehicles. This result can also be drawn from Figure 7, which depicts the change in the average number of calls in each emergency vehicle request line with various incident occurrence rates. It is seen that as the incident rate increases, the demand for tow trucks increases faster than the demand for any other emergency vehicles. Hence, it seems beneficial for the center to select tow truck among emergency vehicles to be increased in number.

Table 5 Simulation Statistics for the current network shown in Figure 4

Average Incident Duration (min)	85.626
Average Detection Time (min)	16.034
Detection by Patrolling Units	34.46%
Utilization of Fire Trucks*	0.03376
Utilization of Tow Trucks	0.46552
Utilization of Ambulances	0.23626
Utilization of Clean-Up Service	0.01614

* Utilizations have a range between 0 and 1, where 0 represents idle, and 1 represents busy.

[3] Since the simulation run time is long enough, warm-up period is not considered.

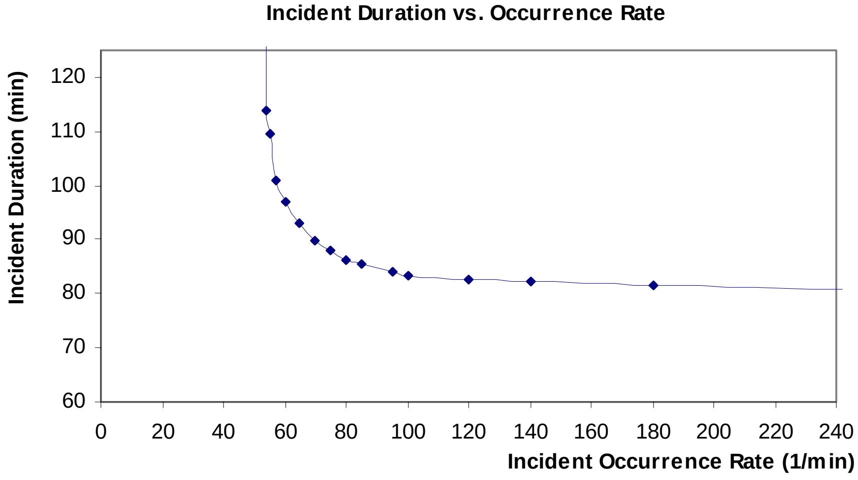


Figure 5 Incident Duration variation with respect to several incident occurrence rates

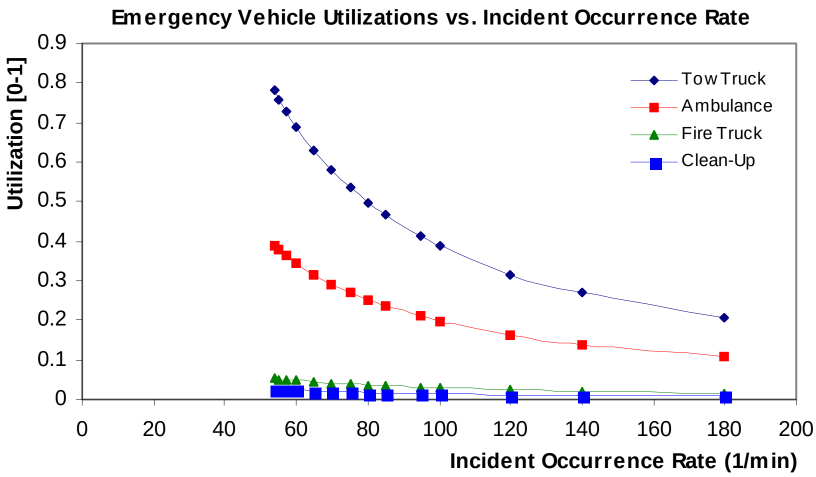


Figure 6 Utilization of emergency vehicles with the increasing incident occurrence rate

Next step is to determine the optimal or near-optimal location of the additional tow truck in the network in a way that the system reaches an optimal efficiency in terms of reduced incident delays. We examine several locations in the network, calculate the average incident durations and compare the results for each trial.

The 6 trial locations for the new tow truck are shown in Figure 8. We run the simulation for each case with the same postulated incident occurrence rate (*85* mins) for one year. The results of the simulation shows that the average incident duration is reduced by approximately *2.5* minutes with the new ERT deployment, and the delay reductions in each case does not vary from each other (Table 6). We shall employ the 1st trial location, which has the least incident duration.

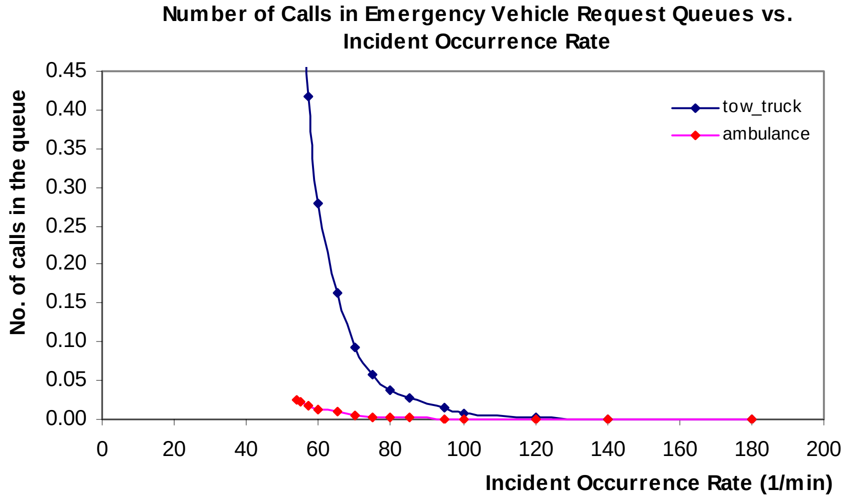


Figure 7 The variation in number of calls in emergency request lines with respect to several incident occurrence rates (Fire truck and clean-up statistics are not included, since their values are insignificant)

Table 6 Incident durations for each trial location of the additional tow truck in the network

	Incident
Trial	*83.17 min*
Trial	*83.59 min*
Trial	*83.74*
Trial	*83.62*
Trial	*83.62*
Trial	*83.55*

After determining the new emergency vehicle with its location in the network, we examine the effect of an additional patrolling unit on the average incident duration. We hold the number of emergency vehicles same as in the original ERT deployment (*4* tow trucks, *4* ambulances, *4* fire trucks and *1* clean-up), and increase the number of patrolling units by one. We examine *5* different routes for the additional patrolling unit. These routes are given in Table 7. The network is simulated for one year for each case.

The analysis shows that, with the introduction of an additional patrolling unit, average detection time is reduced by *1.5* minutes and the percentage of incidents detected by patrolling units increased from *34.46*% to *46.05*%. The results are shown in Table 8. The incident durations for each trial are found to be the same.

Comparing the results given in Tables 6 and 8, it is seen that under FIFO dispatching policy, the effect of an additional tow truck on incident duration reduction is more than that of an additional patrolling unit. However, the results are not significantly different from each other. Thus, in order to reinforce our results, we decided to compare these two ERT deployments under various incident occurrence rates. Assuming that the optimal location for tow truck and the optimal route for the patrolling unit remain the same as before, we simulated each ERT deployment for one year for different incident occurrence rates. The results are depicted in Figure 9. It is clear that the results are heavily dependent on incident occurrence rates. For example, at small incident occurrence rates, patrolling unit seems more efficient (terminal point on y-axis is lower than that of the setup with an additional tow-truck). On the other hand, at higher incident occurrence rates, the system with an additional tow truck can handle the incidents better.

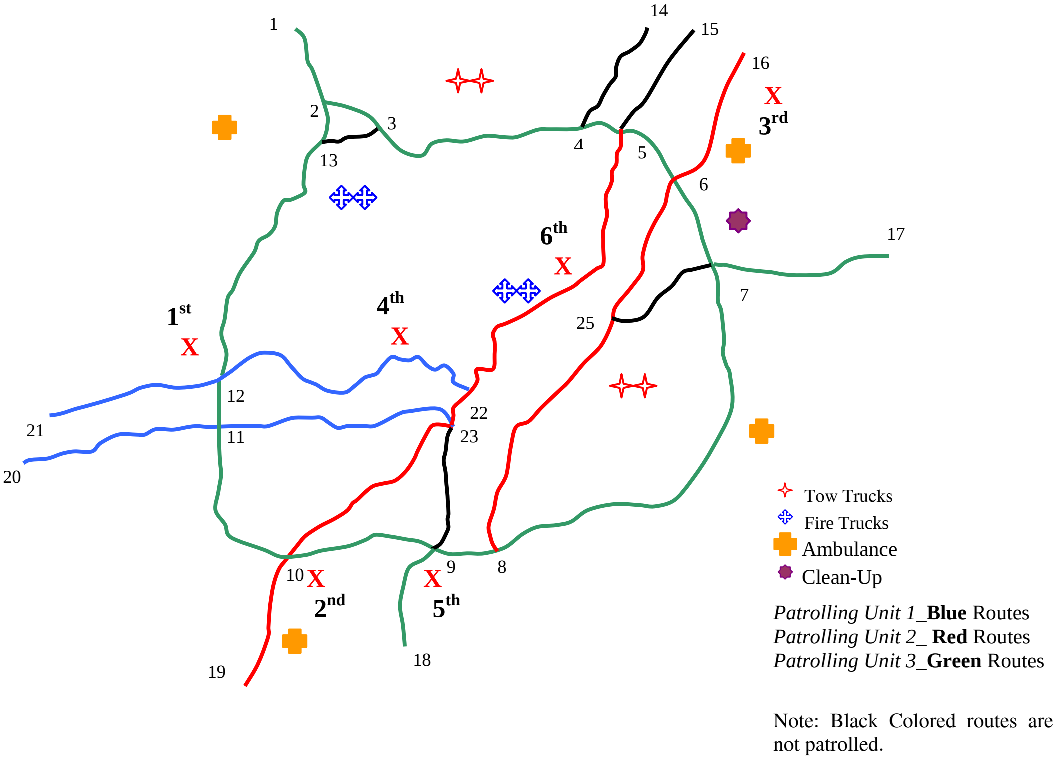


Figure 8 Trial locations for the new tow truck in the network.

Table 7 Trial Routes for the additional patrolling unit*

Trial	7-8-25
Trial	15-5-22-23-9-18
Trial	1-2-13-12-11-10-19
Trial	The same route of patrolling unit 3
Trial	The same route of patrolling unit 1

- The numbers represent the intersections in the network as shown in Figure 8

Table 8 Incident Durations and Detection Percentages for the trial routes of the additional patrolling unit

	Incident	**Detection**
Trial 1	*84.926 min*	*38.97%*
Trial 2	*84.615 min*	*41.92%*
Trial 3	*84.549min*	*41.61%*
Trial 4	*84.092min*	*46.05%*
Trial 5	*84.999 min*	*38.33%*

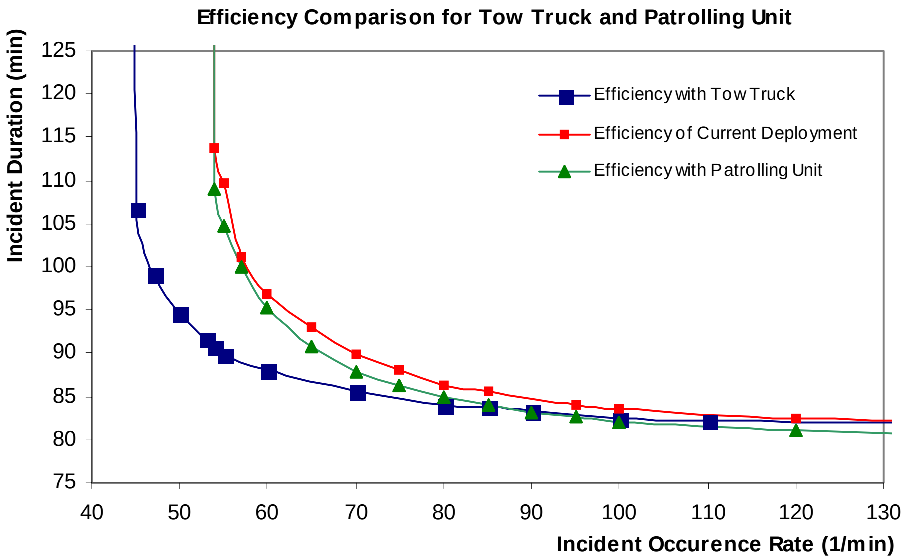


Figure 9 Comparison of the system capabilities for each strategy

Also, a careful observation of the graphs in Figure 9 yields an interesting interpretation of the analysis. As mentioned before, the terminal point on x-axis of the current ERT deployment is reached at an incident occurrence rate of *54* minutes, which results in an incident duration of *113.701* minutes. It is observed that the ERT deployment with an additional tow truck reduces this duration by *22.887* minutes to *90.814* minutes at the same incident occurrence rate. Also the terminal point on x-axis of the current setup shifts from *54* minutes to *45* minutes with the additional tow-truck, whereas remains the same with the additional patrolling unit. On the other hand, if patrolling units cannot detect the incident, our postulated default incident detection and verification time was *20* minutes. Hence, at the *terminal point*, no matter how many patrolling units are utilized, the resulting reduction in incident duration will not be greater than *20* minutes. Hence, for higher incident durations, one additional tow truck will help the system to remove incidents more than any number of patrolling units.

Thus, it can be concluded that, it is beneficial for the management center to invest on tow truck as a new emergency vehicle under FIFO policy.

6. Conclusions

In this paper, a simulation model is developed to evaluate the effectiveness of incident management strategies for Washington, D.C. beltway network. For the example scenario presented in Section 5, reductions in incident durations for several strategies are estimated using this simulation model.

Based on the postulated network properties, the additional tow truck reduces the incident duration more than an additional patrolling unit. Although, the results are highly dependent on incident occurrence rates, it is shown that an additional tow truck in the system is more effective in reducing incident durations especially in the long term, where there is always a possibility of having a higher incident occurrence rate. More interestingly, the analyses have shown that in higher occurrence rates, additional emergency vehicles help the system more than any number of patrolling units.

Different transportation networks have different characteristics. It is therefore not easy to validate our results using absolute numbers. However, we can compare our simulation results with existing real-world studies in terms of trends predicted in our paper.

Tables 6, 7 and 8 present hypothetical scenarios for which the location of the additional response unit is changed or an additional patrolling unit is added to one of the pre-selected routes. Since these are hypothetical scenarios, real-world data to validate its results does not exist. However, the study by Skabordanis et al. (1998) supports the positive impact of FSP (freeway service patrol) by the drastic difference between the duration of incidents assisted by FSP and incidents that are not assisted by FSP. Skabordanis et al. (1998) reports that the reduction in the overall incident duration due to FSP was found to be *15* minutes on the average, around *40*%.

Figure 7 simply shows the fact that the demand for ambulances is less than the demand for tow trucks since most of the incidents are not severe enough to warrant the need for an ambulance. The large number of less severe accidents, which do not require medical attention is a well-documented fact depicted in Skabordanis et al. (1998), Sullivan (1996) and Ozbay et al. (1997).

As it is also mentioned in Skabordanis et al. (1998), the introduction of Freeway Service Patrol is shown to have a significant effect in the reduction of incident durations, mainly due to the reduction in incident detection /response times. More specifically, the study of California Highway patrol database showed that average incident duration during the off-peak with no FSP is 35% longer than the incidents with FSP service. In the same study, in district 7 in California, the difference in using FSP versus not using them appeared to be clearer. On the average, FSP assisted incident durations were 41% higher than non-FSP assisted incidents. Although we examine the effect of only one additional patrolling unit in the network, this trend is captured by our simulation model as shown in Figure 9. Use of patrolling units reduces the incident durations, especially at higher occurrence rates where timely detection and verification of incidents becomes the most important factor that reduces incident durations.

Finally, our methodological contributions can be summarized as follows:

i. We developed a complete simulation tool using *Siman* simulation language that can be used to evaluate the effectiveness of incident management strategies that involve different types of response vehicles and traffic conditions. The existence of such a tool makes it possible to easily evaluate the impacts of additional as well as existing incident management resources. This can be a valuable tool for incident management planners who would like to improve their existing operations.

ii. We used a real network and real-world data collected by one of the authors of this paper to test the developed simulation model. Thus, the results of our simulation model can be better validated due to the familiarity of this author with the simulated network. This is a major contribution given the lack of reliable input data for this kind of studies conducted in the past. It should be mentioned that the results presented in this study are specific to the selected network, and should not be generalized for other networks.

iii. The use of a robust and well tested simulation development package such as ARENA enables us to focus on the problem domain namely, incident management, rather than the programming of simulation specific functions

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