A Simulation Model for
Real-Time Emergency Vehicle Dispatching and Routing

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ABSTRACT

In this paper we develop a simulation model to evaluate a real-time Emergency Medical Service (EMS) vehicle response system that uses real-time travel time information and assists the emergency vehicle dispatchers in assigning response vehicles and guiding those vehicles through non-congested routes. Different response strategies are evaluated using this simulation model. These include the First Called, First Served (FCFS) strategy, the nearest origin assignment strategy, and the flexible assignment strategy that uses real-time travel time information for assigning and dispatching response vehicles. Different assumptions and conditions are used to test the sensitivity of the flexible assignment strategy.

Key Words: Emergency Response, Optimization, Simulation, Real-time, Routing, Dispatching
1. INTRODUCTION AND PROBLEM STATEMENT

An incident that requires emergency response can range from minor events that can be handled by a single emergency response vehicle to very major ones that involve fatalities or hazardous material spills that require multiple vehicle response and can take a long time to clear. These incidents have a profound impact on the surrounding transportation network operation. Fleet management represents the process by which emergency response vehicles are assigned and routed to handle accidents.

In case of emergencies the response time plays a crucial role in minimizing the adverse impacts. Fatalities and loss of property can be greatly reduced by reduction of the response time to accidents. Traffic congestion, on the other hand, increases the travel time for the emergency response vehicles and may increase the response time accordingly.

Traffic congestion and delay are significant problems in most large urban areas since they substantially increase the user’s cost. “CHART Incident Response Evaluation Final Report” (1996) showed that in 1987 the nationwide total delay was 2.0 billion vehicle hours per year. The 1992 annual delay was about 4.0 billion vehicle hours. Based on traffic forecasts provided by all major metropolitan areas, the total nationwide delay was expected to reach 8.0 billion vehicle hours by August 2005.

Normally, incident response time is the time between receiving a call at the dispatch center and the arrival of the first emergency response vehicle on the scene. The duration of the dispatch time depends on the emergency service vehicle availability. It is a function of the generated workload for emergency medical services, i.e. number, spatial, temporal, and severity of the incidents. If the incident rates are not high, the capacity of the system can deal with all service requirements. In this case, the duration of the dispatch time is relatively constant. If this is not the case, a server’s queue is created in which the incidents wait for available response vehicle. This paper focuses on the travel time component of response time since this is the component most affected by dispatching and routing decisions. Travel time depends on the travel speed of the emergency response vehicles and the size of their service area. Besides this, this time substantially depends on emergency response vehicle management that includes dispatching strategy and route determination. Therefore, accident restoration time, and consequently the performance of the emergency response system, can be enhanced substantially by reducing travel time.

In this paper we develop a simulation model to evaluate several emergency response vehicle dispatching strategies. These include the First Called, First Served (FCFS) strategy, the nearest origin assignment strategy, and the flexible assignment strategy that uses real-time travel time information for assigning and dispatching response vehicles. The flexible assignment strategy assigns vehicles to emergencies based on their current location, the real-time traffic and travel time information and the type and severity of the incidents. This assignment is done through an optimization model that minimizes the overall response time subject to service constraints. This model is described in detail in another paper by the authors (Haghani et al., 2002). Different assumptions and conditions are used to test the sensitivity of the flexible assignment strategy.
2. LITERATURE REVIEW

The earliest papers in the literature on dynamic vehicle routing and dispatching were presented in the seventies and were either application-oriented (Wilson and Colvin, 1977) or analytical (Daganzo, 1978; Stein, 1978).

By the end of the eighties, dynamic vehicle routing gained increasing attention. Two major factors explain this tendency: new developments in information technology and the need for decision systems that could exploit this information to better represent the real world. Interesting survey articles on dynamic vehicle routing can be found in Psaraftis (1988), Powell et al. (1995) and Lund et al. (1996).

Because real-time vehicle routing problems are NP hard and quick response times are required, exact algorithms are not yet capable of handling problems of realistic sizes (Psaraftis, 1980, 1983; Dial, 1996). This justifies the use of simulation models in real-time environments. Savas (1969) used simulation as a tool to perform a cost-effectiveness analysis of New York’s emergency ambulance services. He proved that dispersion of ambulances improves the efficiency of the EMS system. Larson (1974) used the hypercube queuing model, which incorporates theoretical queuing theory results and simulation as a tool in dispatching of police patrol cars. Brandeau and Larson (1986) extended the use of the hypercube model to deployment of emergency ambulances.

Ignall et al. (1978) used simulation to suggest approximate analytical models to be used for police patrol and fire operations in New York City. The link between simulation and analytical models has been further analyzed and evaluated in a paper by Shantikumar and Sargent (1983), in which several uses of these hybrid models are suggested. Zografos et al. (1993a) developed a simulation model for studying the trade-off between freeway accident delay and the size of freeway emergency response fleet, and for studying the effect of alternative dispatching strategies on the performance of the freeway emergency response fleet. Goldberg et al. (1990) developed a simulation model for evaluating alternative base locations for an emergency response fleet in Tucson, Arizona.

Kim et al. (2002) considered a dynamic (online) truckload routing and scheduling problem with time windows operating in over-saturated conditions. That is, the average demand arrival rate exceeds the capacity of the fleet to provide service within acceptable time windows, and the inter arrival time between successive demand requests is very short. In this paper, instead of accepting and serving all the demands, they made intelligent acceptance and filtering decision procedures that consider system status and demand characteristics. It can result in significant operational benefits for system efficiency and response time.

The majority of existing EMS models deal with the following two subjects: 1. Location of ambulance stations within a region and satisfying requests for service subject to some performance criteria. 2. Determination of the minimum number of ambulances to serve all calls for service within a given area.

There are also several models dealing with some other aspects of EMS planning, such as, dispatching strategies and their influence on performance results, and multiple casualty accidents. However, none of them uses dynamic travel time information or considers vehicle diversion and route changing. In this research, the performance of alternative emergency
vehicle dispatching strategies is evaluated on the basis of dynamic travel time information. Moreover, vehicle diversion and route changing are also taken into consideration.

3. MODEL DEVELOPMENT

A simulation model is developed for a real-time emergency response vehicle dispatching system. At each simulation point, the program updates the accident and vehicle information. The information to update for a vehicle includes: the current location, the route to take, the destination, the time to have the next status change, the current status, and the next proposed status. All the information must be updated at each step. The information for an incident to update includes: the current status of the incident, and the required response time. A flowchart of this simulation model is shown in Figure 1.

3.1 Assumptions

In developing the simulation model the following assumptions are made:

1. According to the severity and the number of persons and vehicles involved in the emergency, five types of emergency are categorized. Types 1 through 5 indicate the most severe through the least severe accidents respectively. Different types of emergencies require different maximum response times and service times. Most severe accidents require shorter maximum response times and longer service times. For the two most severe types of emergencies, besides on-scene service, it is required that the persons involved are transported to hospitals for further care.

2. All call arrivals are independent of each other and are assumed to follow a Poisson distribution. It means that this system is an M/G/P (Poisson arrival, general service times and p service units) queuing system but with distinguishable service units. Moreover, the service times are dependent on the state of the system, where a state of the system is a description of the status of each server: busy or free and the type of the emergency it serves. Due to the property of queuing systems, it is obvious that exactly one response unit is assigned to every call and the service time is independent of the identity of the server, the location of the customer, and the history of the system.

3. Incidents happen at the nodes and no more than one accident happens at the same node at the same time. That is, a new accident service request from a particular point can only occur after the completion of the previous on-scene service. Although this assumption may seem to be restrictive because in real networks many incidents happen along the links, it can be easily relaxed. The optimization model that assigns vehicles to incidents works with a dynamic network. In this network, nodes can be added as required and each vehicle is treated as a "moving node." Therefore, any incident location can be added to the network as a node and handled as such.

4. A minimum time period is required for a vehicle between the time when the vehicle comes back to its station and the time it is reassigned for service so that the vehicle can get equipped and maintained. Once an emergency vehicle finishes a delivery to hospital or on-scene service, and it doesn’t have new assignment, it will go back to its station.
In developing the simulation model we used the transportation network of Arlington County, VA as the study network in this research. 38 nodes and 62 links are used to represent the network as shown in Figure 2. The nodes indicate the locations of the main intersections and the hospitals and the links indicate the main roads. There are ten emergency response vehicles located at ten stations in Arlington County.

Information obtained from analysis of the existing data was used to develop probability density functions describing (a) the temporal distribution of the request calls, (b) the spatial distribution of the request calls, and (c) the priority distribution of the request calls. Because the rate of incident arrival depends on time of day, for example, at night there are less incidents, in this research, we focus on the incidents happening during daytime, from 6 am to 8 pm. The temporal distribution of the request calls follows a negative exponential, while the spatial and the priority distribution of the request calls are both uniform with different weights. In addition, the average travel time between the nodes of the network was calibrated using travel time information provided in the database.

3.2. Travel Time Prediction Method

Based on the network shown in Figure 2, the relative horizontal and vertical coordinates for every node representing an intersection are set up. Then on the basis of historical travel time information, an adjustment coefficient is applied to the distance between adjacent nodes to get an average off peak travel time $\lambda_{ij}(t)$ between the nodes $i$ and $j$. For the average peak travel time between any two adjacent nodes, we assume that it is 1.8 times the off peak travel time and there are two peak hours per day. They are from 7am to 9am and from 4pm to 6pm, respectively. And we assume that the historical average travel time considers all factors that affect travel time, such as incidents, congestions, and signal controls, etc. The variance of travel time caused by these factors is small since emergency vehicles always use siren when they are undertaking a task.

When calculating travel time $T_{ij}(t)$, we use a normal distribution with a mean equal to the average travel time to represent the distribution of travel time on a particular link at time $t$.

The mean $\mu_{ij}(t)$ is equal to the average travel time and the variance $\sigma_{ij}^2(t)$ is equal to ten percent of the average travel time. The relationships are as follows:

$$\mu_{ij}(t) = d \cdot \lambda_{ij}(t)$$

$$\sigma_{ij}^2(t) = \mu_{ij}(t)/10$$

$$T_{ij}(t) \sim N(\mu_{ij}(t), \sigma_{ij}^2(t))$$

$d$ is a coefficient used to calculate travel times on the basis of average off peak travel times. $T_{ij}(t)$ is the predicted travel time for a particular link starting at time $t$ based on the current situation.

Since we don’t know what will happen during the interval $[t, t + \Delta t]$, it is possible that something will cause the travel time to change significantly. In this research, for
simplicity, we predict $\hat{T}_{ij}(t)$, the predicted travel time, as the average of $T_{ij}(t)$ and $\mu_{ij}(t + T_{ij}(t))$, where $\mu_{ij}(t + T_{ij}(t))$ is the average travel time on the same link after a time interval $T_{ij}(t)$. Therefore, $\hat{T}_{ij}(t) = \left( T_{ij}(t) + \mu_{ij}(t + T_{ij}(t)) \right)/2$.

3.3. Assignment Strategies

The real-time assignment sub-problem of dynamic vehicle allocation and routing problem is concerned with assigning newly arriving request to specific response vehicle and modifying existing assignments as changes happen in the system. The following three assignment strategies are studied in this research:

1. First Called, First Served (FCFS)
2. Nearest Origin Assignment and (NO)
3. Flexible Assignment Strategy (FA)

The FCFS strategy assumes the service calls are assigned to available vehicles in the order in which requests are received. Service requests are added to a queue of requests on arrival; when a vehicle becomes available, it is assigned the first request in the queue. If one (or more) vehicles is (are) idle when the request arrives. The request is assigned to the vehicle that has been idle longest. A driver must contact the dispatch center upon completion of service.

In nearest origin assignment, service requests enter the pool of unassigned requests. Upon assignment completion, the driver contacts the dispatch center for a new assignment, at which time an assignment is made to the nearest unassigned request. Service calls arriving when one or more vehicles are idle are assigned to the nearest idle vehicle. A driver must contact the dispatch center upon completion of service.

In the flexible assignment strategy, service requests enter the pool of unassigned requests when all vehicles are busy, or the idle vehicles cannot reach the emergency spot in maximum required response time. At each simulation time point, the dispatch center will optimize the current assignment so as to minimize total response time according to associated weights of different classes of emergencies. Therefore, en route diversion and reassignment of vehicles to emergencies are allowed in this strategy. Namely, responding vehicles can change their current route or destination under the guidance of the dispatch center. To avoid changing route or destination of vehicle so frequently that the driver gets confused and makes mistakes, there are minimum required improvements associated with the class of emergency that must be satisfied when making a change.

3.4. Simulation Modules

An essential step in developing the simulation model is to generate different modules, such as accident module and vehicle module. The data structures for accidents and vehicles in the program are both lists that contain all kinds of necessary information.
3.4.1. Accident Module

The accident list contains the following information: (a) the temporal distribution of the service calls, (b) the spatial distribution of the service calls, (c) the priority distribution of the service calls.

3.4.2. Dispatch Center

At each simulation time point (receiving a new service call, vehicle status change from “busy” to “available”, or at an incremental time point), the dispatch center runs the program and makes decision about the movement of all vehicles according to an assignment strategy and the result of simulation. So it is the brain center of the operation, receiving and processing all service calls and controlling all activities.

3.4.3. Vehicle Module

Each response vehicle in the fleet represents a working crew and provides emergency medical service. Various classes of vehicles, with varying attributes that affect their functionality and ability to respond to particular types of request, could be represented. In this research, only one class is considered because of the real situation in Arlington County. So vehicles are essentially substitutable. From a simulation standpoint, vehicle activities are described by keeping track of the location, the status, the destination and the path to destination for each vehicle. The nodes representing the vehicles are “temporary” and “movable”. That is, the nodes are attached and move together with the vehicles. At any given instant, each vehicle has an associated status. A vehicle changes status at the occurrence of certain events that mark the occurrence of service call or the completion of the corresponding activity. For instance, a vehicle status changes from “idle at station” to “on the way to an emergency spot” on receiving an assignment from the dispatch center.

3.4.4. Simulation Time Advances

The simulation time advance process in this research is by “event” and “fixed time increment”. That is, the process is event-driven as well as time-driven. During the interval of any two simulation points, the system smoothly follows the best solution in memory.

When an accident happens or a vehicle changes its status, such as from “busy” to “free”, we should update related variables according to these events. Formulation and re-dispatching may be performed at these time points.

The simulation is based on real-time traffic data. So it is not surprising to reconsider our dispatch decision after some time interval even though there are no “events” during this “interval”.

Events

The events include the “accident” part and “vehicle” part. The accident part is referred to the “arrival” of a new accident. The “disappearance” of accident should also be included in the “vehicle” part, since the corresponding response vehicle will change its status once the on scene service is accomplished. But the accident and vehicle in the system
are not independent because vehicles are corresponding to some accidents. It is observed that when a vehicle changes its status from "on the way to an accident \( X \)" to "service an accident \( X \)" that means the accident changes its status from "waiting for service" to "in service". Or if a vehicle changes its status from "serve an accident \( X \)" to "on the way to hospital \( Y \)" that means the accident is removed from the "accident list" under consideration. Tables 1 and 2 list the current status for vehicles and accidents and the status to which they change.

The vehicle status change is tightly related to the accident status change. Furthermore, some vehicle status changes may result in the reconsideration of the dispatching decision. For instance, if a vehicle finished its task and it is on its way back to depot, that means the vehicle is “free” at this point. We may assign it to an accident point. So the formulation and re-assignment is needed upon this event.

**Time Increment**

Since the traffic situation will affect the travel time and thus affect the route of emergency vehicles, it is necessary to check our vehicles’ route occasionally. It is also possible to change their destination at some points.

There are “event series” and “time increment” to drive the simulation process. We will rank these time points and select the earliest one as the next simulation time point.

In each simulation point, the program will update the accident and vehicle information. The information for vehicles to update includes: the current location, the route to take, the destination, the time point of next status change, current status, next proposed status, etc. Each vehicle in the studied network is treated as a “moving” node. If the position of vehicle has changed, the program will update the adjacency matrix and shortest path between each pair of nodes simultaneously.

The information for an accident is relatively simple. That is because some accident information is recorded by the corresponding vehicles. The information to update includes adding or removing an accident and the remaining time to the required time limit.

**3.4.5. Traffic Generation**

For real world implementation real-time traffic information should be available to the EMS dispatching center through communication with the transportation management center. However, in order to run the simulation and test the dispatching model, a traffic generation module is required to build a complete simulation framework.

The average flow for each time period (for example, AM and PM peak hours) is also assumed available. Typically, there are AM and PM peak hours for weekdays and a midday peak hour for weekends.

Traffic volume \( q_{ij}(t) \) over link \( ij \) at current time \( t \) will be generated as a random variable with normal distribution \( N(\mu_{ij}(t), \sigma_{ij}(t)) \), where \( \mu_{ij}(t) \) is the average flow rate at time \( t \), and \( \sigma_{ij}(t) \) is proportional to \( \mu_{ij}(t) \). With the flow rate generated above, the travel speed on each link is determined using a unique speed flow relationship for that link.
3.4.6. Dynamic Shortest Path Algorithm

A discrete approach for determining the dynamic shortest paths is selected for this research. Most recent research in dynamic shortest path algorithms concentrates on discrete approaches. Discrete dynamic shortest path algorithms are developed and tested successfully. The research in continuous approaches is quite limited and no algorithm is proved to be successful in implementation. The algorithm for computing the dynamic shortest path between each O/D pair and each starting point is available in literature (Ziliaskopoulos and Mahmassani, 1993).

4. ANALYSIS RESULTS

Object-oriented C++ programs are developed to simulate the system under alternative dispatching strategies. For the Flexible Assignment strategy, at every simulation point, the program will prompt CPLEX to optimize the assignment (Haghani et al. 2002). In the programs, we keep records for all vehicles and accidents so that we can perform statistical analysis and create input files for ARENA for animation. The records for vehicles include their trajectories, the time when they visit a node, and the paths to their destinations at each simulation point; the records for accidents include the type, the time of occurrence, the time of arrival of the response vehicle, and the time of accident restoration.

In this research, several comparisons and sensitivity studies are made. They are (1) comparison between different dispatching strategies; (2) comparison between static and dynamic travel time; (3) comparison between static and dynamic assignments; (4) impact of the criteria to change route; (5) sensitivity analysis to travel time variance. The results are illustrated in Figures 3 through 5. Static assignment means that vehicles cannot change their tasks while en-route until they finish their previous assignments. The FCFS and the Nearest Origin dispatching strategies are of this type and are based on static travel time information. On the other hand, dynamic assignment means that vehicles can change their tasks while en-route. The Flexible Assignment dispatching strategy is of this type and is based on dynamic travel time information. Dynamic assignment is a result of en-route task change policy based on dynamic travel time information in the system.

To compare alternative dispatching strategies under different accident occurrence rates, we consider average response time, maximum response time and the ratio of accidents whose response time exceeds the pre-specified response time limit to total accidents. These are referred to over-waited accidents. The average response time is the main criterion to judge a dispatching strategy since it plays a crucial role in minimizing the adverse impacts. Meanwhile, from the maximum response time, we can identify the worst case of the system. For the ideal system or in case the accidents are not too frequent, it is possible that all response times are within the pre-specified response time limit. However, with the increment of the frequency of request calls for service, the system cannot ensure this principle. Therefore, we keep records of the ratio of over-waited accidents to total accidents.

The following observations can be made:

1. Figure 3 indicates that regardless of considering static or dynamic travel time information, the Flexible Assignment dispatching strategy performs better than the Nearest Origin and the FCFS dispatching strategies in terms of the average response time, and the Nearest Origin dispatching strategy is better than the FCFS dispatching strategy. When the time interval between two consecutive emergencies is small, namely, when request calls are...
more frequent, the advantage is more dominant. For instance, under dynamic travel time information, when the interval is equal to 8 minutes, the average response times for the FCFS, the Nearest Origin, and the Flexible Assignment dispatching strategies are 11.78, 5.27, and 4.33 minutes respectively, while when the interval is equal to 2 minutes, they are changed to 23.44, 17.23, and 7.0 minutes.

2. With the increment of the time interval between two consecutive emergencies, the average response time will decrease gradually because of less request calls. However, at some point, the average response time will rebound a little. That is because of the assumption that vehicles are required to spend a minimum time period between the time when they arrive at the station and the time they are reassigned for service at the station so that they can get equipped and maintained. At higher time intervals, more vehicles will return to the stations after finishing service at the scene or delivery to a hospital.

3. When the time interval is quite small, the average response time changes dramatically with its change. For example, when the interval changes from 2 minutes to 2.5 minutes, the average response time changes from 23.44 minutes to 13.17 minutes for the FCFS dispatching strategy, 17.23 minutes to 9.33 minutes for the Nearest Origin dispatching strategy, and 7.00 minutes to 6.06 minutes for the Flexible Assignment dispatching strategy under dynamic travel time information. That means for each dispatching strategy, the capacity of the system for requests for service is different. Beyond this capacity, the system will become very busy and the workload for each emergency vehicle is so high that it takes a long wait time for accidents before service.

4. The average response time will remain stable when the time interval increases to a certain level. The reason is that the interval is so high that each vehicle has nothing to do except for going back to the station after becoming available. This represents a situation in which the system has enough capacity to handle all requests for service.

5. Figure 4 shows that dynamic travel time information is quite helpful for reducing emergency response time.

6. Table 3 shows that with the increment of the route change critical value, the average response time, the maximum response time and the number of over-waited accidents increase, while the total number of times vehicles change routes decreases.

7. Dispatching strategy plays an essential role for minimizing the total response time in comparison with travel time variation.

5. **CONCLUSIONS AND FUTURE RESEARCH**
   
   In this research, a simulation model is developed to evaluate alternative emergency vehicle dispatching strategies in order to minimize average response times associated with different types of accidents. Alternative assignment strategies were analyzed to test the performance of this model under various circumstances, namely, different accident occurrence rates, route change strategies and dynamic travel times. We used a real network and real-world data provided by Arlington County Fire Department to test the developed simulation model. It shows that it is valuable to apply flexible assignment strategy in real-world operation in order to reduce accident restoration time.
In this research, for flexible assignment strategy, CPLEX is used to optimize the assignment at each simulation time point. This can be done because the size of the test network is small enough so that the calculation time at each iteration is negligible. However, for real world networks that are more detailed for more precision, the calculation time will increase and cannot be ignored. In this case, a heuristic is needed to replace CPLEX so as to achieve an acceptable calculation time.

In this study, only one type of emergency response vehicle is considered to handle all types of accidents. For a given accident it is possible that different types of emergency response vehicles would be needed or more that one vehicle would be necessary. Handling these situations is another area for future research.

For a large network, it is more reasonable to consider incidents happening on both nodes and links. In this research, we just consider the situation that incidents happen only on nodes, so we didn’t consider the directions of approach for emergency vehicles. For the future work, the directions of approach for emergency vehicles should be taken into account when they are assigned to deal with incidents happening on links.

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REFERENCES


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FIGURE 4 Comparison between Static and Dynamic Travel Times (FCFS)
FIGURE 5 Comparison between Static and Dynamic Assignments
### TABLE 1

Change of Status for Response Vehicles

<table>
<thead>
<tr>
<th>Current Status</th>
<th>Next Status to Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle at station (L)</td>
<td>On the way to an emergency spot (M)</td>
</tr>
<tr>
<td>On the way to an emergency spot (M)</td>
<td>Dealing with an emergency at spot (N)</td>
</tr>
<tr>
<td>Dealing with an emergency at spot (N)</td>
<td>Leaving for a hospital (H) or Driving back to station (O)</td>
</tr>
<tr>
<td>Leaving for a hospital (H)</td>
<td>Driving back to station (O)</td>
</tr>
<tr>
<td>Driving back to station (O)</td>
<td>Idle at station (L) or on the way to an emergency spot (M)</td>
</tr>
</tbody>
</table>

### TABLE 2

Change of Status for Emergencies

<table>
<thead>
<tr>
<th>Current Status</th>
<th>Next Status to Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting for service (W)</td>
<td>In service (I)</td>
</tr>
<tr>
<td>In service (I)</td>
<td>Disappearance</td>
</tr>
</tbody>
</table>

### TABLE 3

Impact of Criterion for Route Change

<table>
<thead>
<tr>
<th>Criteria</th>
<th>$\tau$ (min.)</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
<th>4.0</th>
<th>5.0</th>
<th>6.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average response time</td>
<td></td>
<td>4.96</td>
<td>5.12</td>
<td>5.18</td>
<td>5.23</td>
<td>5.41</td>
<td>5.56</td>
</tr>
<tr>
<td>Maximum response time</td>
<td></td>
<td>17.30</td>
<td>17.30</td>
<td>17.10</td>
<td>18.1</td>
<td>20.7</td>
<td>21.2</td>
</tr>
<tr>
<td>Number of over-waited accidents</td>
<td></td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Total number of times the vehicles change routes</td>
<td></td>
<td>20</td>
<td>15</td>
<td>13</td>
<td>10</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>
Generate Traffic Flow

Predict Travel Time

Calculate Dynamic Shortest Path

Generate Emergency Incident

Update Incident and Vehicle Information

Select the Next Simulation Point

Assign Vehicle (Using Formulation)

Change Emergency Vehicles’ Destinations or Routes

Update System Time

Figure 1

Conceptual Simulation Flow Chart
FIGURE 2

Arlington County Network
(a) Static Travel Time Information

(b) Dynamic Travel Time Information

FIGURE 3

Comparison between Different Dispatching Strategies
FIGURE 4
Comparison between Static and Dynamic Travel Times (FCFS)
FIGURE 5

Comparison between Static and Dynamic Assignments