ABSTRACT

Title of Thesis: DEVELOPMENT OF AN INTEGRATED NETWORK SIMULATOR FOR REAL TIME TRAFFIC MANAGEMENT: I-95/US-1 TRAFFIC SIMULATOR

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This study presents a network simulator that integrates the knowledge base with a microscopic traffic simulation model for real-time traffic management. The proposed system offers three main functions: incident management, work-zone operations and recurrent congestion monitoring. The knowledge base is used to inventory the operational experience and traffic impacts associated with all previously recorded incidents. Such information will be used along with an embedded prediction module to estimate the duration of a detected incident.

The proposed system will enable traffic control operators to perform two critical tasks during the incident management period: (1) establishing a reliable estimate of traffic impacts; and (2) performing a subsequent real-time analysis of network traffic conditions. The simulation results will also offer information for estimating travel time at varying departure times for different origins and destinations during the period of incident operations.

DEVELOPMENT OF AN INTEGRATED NETWORK SIMULATOR FOR REAL TIME TRAFFIC MANAGEMENT: I-95/US-1 TRAFFIC SIMULATOR

by

Nan Zou

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Chapter 1. Introduction

1.1. Motivation

Efficient response to traffic events have been a significant challenge for highway traffic agencies across the county over the past decade. Despite the emergence of Intelligent Transportation System (ITS), traffic management programs are constantly working to find new strategies for addressing problems. One of the critical challenges faced by traffic management centers is the development of a system that can reliably project the traffic impacts caused by non-recurrent and recurrent congestion. Using variable message signs (VMS) at proper locations, implementing detour plans at critical points, and reporting traffic conditions through highway advisory radios (HARs), allows traffic control operators to deploy (Advanced Traveler Information Systems/Advanced Traffic Management Systems) strategies to prevent the formation of traffic queues, and to mitigate congestion levels cause by traffic events.

To provide a reliable estimate of traffic impacts during incident management or work-zone operations is a challenging task. Traffic conditions (such as queue length, average delay, or speed) on roadways distressed by an incident or on-going work-zone operations may vary in nature based on a number of factors. Examples of contributing factors include the progress of incident clearance efforts, the number of lanes occupied by work-zone operations, the speed and volume of the approaching traffic from upstream segments, compliance rate of a detour operation, effectiveness of VMS, and ramp metering control.

Conceivably, a system that accounts for these factors could be considered user-friendly and capable of minimizing both the learning time and execution efforts of control center operators. In addition, a system that takes into account human-factor issues in the design of the interface could also reduce the error rate of operations and improve the reliability of projected traffic conditions.

1.2. Research Objectives

In response to the aforementioned needs, this study intends to achieve the following objectives:

- Analyze the user needs and required system functions for contending with both recurrent and non-recurrent congestion.
- Construct a knowledge base from previously recorded incidents and build a prediction system to determine the duration of a detected incident.
- Develop the I-95/Route-1 simulator based on all required functions for effectively assessing traffic management strategies in real-time operations.

The knowledge-base/simulation system, named I-95/Route-1 simulator, presented in this study is designed with the above objectives in mind. The proposed system features its capability to offer an immediate estimation of traffic conditions based on its embedded statistical/knowledge-based model, and a detailed analysis of traffic conditions with its microscopic simulation functions. To ensure that potential users under stressed conditions (e.g. during incident operations) can execute the proposed system correctly and efficiently, a GIS type of graphical interface for both the input and output modules have been used for the I-95/Route-1 simulator.

1.3. Organization and Summary

Subsequent chapters of this thesis are organized as follows: Chapter 2 provides a comprehensive review of related literature, and includes the following two sections: review of traffic impact projection, and review of incident duration estimation.

Chapter 3 presents the system framework of the I-95/Route-1 simulator with its three main functions: incident management, work-zone operations, and recurrent congestion monitoring. A flow chart of the six principal system modules is illustrated in this chapter along with a step-by-step description of the operation procedures, which include the input module, traffic management module, knowledge-base module, prediction module, simulation module, and output module. A brief description of key design principles is also presented in this section, and includes the use of on-line and off-line information, accuracy of embedded data, automatic data updating and detection of consistency, minimizing human-factor related errors, and required input efforts.

Chapter 4 presents the principal functions in the I-95/Route-1 simulator designed for traffic operations and management, and includes modeling of the network geometry and detouring operations. Also included in this chapter is a detailed discussion of a specially designed function for updating the network volume through real-time detector data or user input. In addition, the basic geometric and control elements in a transportation system that can be modeled by the simulation are introduced, followed by a description of the logic for updating the time-varying vehicle movement information, which includes volume and turning fractions. The algorithm for automatically checking network volume balance is then presented along with the modeling concept for detour operations in the last section, which includes the input parameters and the function for updating information needed for detour operations.

Chapter 5 presents the prediction module for incident duration estimation that consists of 2 components: an ordered probit discrete model, and a rule-based supplemental module. An exploratory analysis was performed for all the variables available from the knowledge base to construct the discrete model. This is followed by a discussion of the estimation results along with model performance test results. Compared with the incident data in Year 2002, the estimated probit model appeared to provide reasonably accurate estimates for those incidents resulting in less than 60-minute blockage. This chapter also presents a rule-based module for approximating the duration of some types of severe incidents with durations lasting longer than 60 minutes. Other categories of incident scenarios that cannot be reliably modeled with available data are also discussed in this chapter.

Chapter 6 illustrates principal interface functions of the I-95/Route-1 simulator, and includes key features of interface and design principles, such as minimizing the required input efforts, preventing human-factor related errors, automatic data updating, and detection of input consistency. The discussion in this chapter also includes the functions for location identification, input of detail information related to the reported event, volume updates, ramp access control, detour operations, and signal timings. All these functions are presented with system snapshots. A detailed discussion of interface functions for the output module, including chart-based outputs and map-based outputs, are presented with system snapshots in the last section of this chapter.

Chapter 7 presents an example application of the I-95/Route-1 simulator. Recommendations for future enhancement are also included in this chapter.

Chapter 2. Literature Review

2.1. Introduction

Estimating the impacts of non-recurrent congestion (incidents, disabled vehicles and work-zones) is a critical issue for highway traffic agencies. Transportation professionals have been researching this topic for decades. Previous studies have indicated that non-recurrent congestion contributes to major transportation delays (60%), and it will continue to increase to more than 70% in 2005 (Lindley, 1987). Over the years, a variety of methods have been applied to estimate non-recurrent congestion and incident impacts on the transportation network. Many studies focused on the estimation of the incident duration, which is a key factor for determining incident impact.

This literature review is divided into two sections. Section 2.2 summarizes existing studies for assessing incident impacts. Section 2.3 examines literature focused on estimating incident durations. Finally, conclusions and research findings are reported in Section 2.4.

2.2. Estimate of Non-Recurrent Congestion

During the past few decades, significant advances have been made in the development of technologies to analyze non-recurrent congestion for delay, average speed and travel time under traffic events such as incidents and work-zones. Some methods used to examine this problem include shock-waving theory, the deterministic queuing-model, and macroscopic simulation and microscopic simulation. Some attempts have also been made to apply these methods for estimating the incident impacts for real-time applications.

Shock-Wave Theory and Queuing-Theory Based Methods

Messer et al. (1973) attempted to use the kinematic wave theory in predicting individual travel times during freeway incidents. Their test results indicated that the observed travel times were almost always over 10% of the predicted travel time due to the inaccuracy of the estimated wave speeds. Chow (1974) compared the methods of shock wave analysis and queuing analysis for assessing the performance of incident delay calculation. Chow's studies indicated that the use of a time-varying flow-density relationship may lead to more realistic results in calculating total incident delay on a freeway section. Morales (1986) proposed a deterministic approach on the assumption that demand and capacity are constraints in small time intervals. As a result, cumulative delay can be estimated using the linear arrival and departure curves in that method.

Lindley (1987) and Schrank et al. (1990) developed similar methods that allowed comparisons across urban areas with similar indexes of congestion. Lindley obtained data from the Highway Performance Monitoring System (HPMS) developed by the Federal Highway Administration (FHWA) and then developed a computer program for implementing the proposed methods to assess the urban freeway congestion parameters, including congested travel, recurring delay, non-recurring delay, excess fuel consumption, and user costs for the areas covered by the database. Note that the above-mentioned methods are intended only for after-incident analysis, and are not suitable for real-time traffic management which requires more detailed time-varying traffic information.

Macroscopic Theory and Simulation

Al-Deek et al. (1995), Mongeot (2000) and a study from Cambridge Systematics, Inc (1998) have developed macroscopic methods and simulations to assess incident-related impacts. However, the macroscopic simulation, which may perform well in estimating averages for network-wide traffic conditions, cannot provide reliable analysis of local bottlenecks due to incidents. Although time-varying traffic impacts could be estimated with macroscopic simulation, the failure to account for complex interactions between driver responses and traffic conditions may substantially underestimate the impacts incurred by an incident and degrade the resulting reliability for real-time operations (e.g. placing VMS information in time to guide approaching motorists).

Microscopic Simulation

Microscopic simulation has been recognized as an efficient tool for transportation studies in recent years; however, due to the needs of extensive data and familiarity with its complex operating procedures, this type of method has not been used for real-time applications in existing studies (Raub et al. 1998, Zou et al. 2003). The recent advances in computing technologies and graphical interfacing methods have offered the potential for using such a reliable tool for real-time traffic management. For instance, Chang et al. (2000, 2001, 2002) constructed simulators using CORSIM for several freeways and local arterials in the Sate of Maryland, including the entire I-270 corridor, I-95 between I-495 to I-695, I-495 between I-95 and MD97. The execution time of these simulation networks is sufficiently short for real-time incident management. A specially designed interface for each simulator also enables traffic engineers to circumvent the complex modeling and data input efforts, and to conveniently employ the developed simulators for analyzing traffic conditions.

2.3. Estimation of Incident Duration

Incident duration is a key input variable of models and methods for estimating incident impacts. A reliable estimate of incident duration is essential for effective real-time traffic management. Transportation professionals have adopted a variety of methods for estimatinge incident duration. Some of the findings resulting from these practices are briefly discussed in the subsequent subsections.

Probabilistic Distributions

Studies in this area tend to use a simple method to model the duration of an incident as a random variable, and attempt to apply a probability density function to the incident data. From the calibrated distribution, control center operators can approximate the mean and variance of the duration for detected incidents. For example, Golob et al. (1987) analyzed freeway traffic accident data based on 332 freeway and 193 ramp accidents around Los Angeles, California over a two-year period. The authors theorized that the total duration of an incident could be modeled according to a lognormal distribution. Their findings were supported using the Kolmogorov-Smirnov test for all studied incidents.

Ozbay and Kachroo (1999) investigated 650 incidents from Northern Virginia over a period of one year, and found that the incident duration had a shape similar to a lognormal distribution. However, their hypothesis was rejected by several statistical tests.

The researchers concluded that the data for incident duration might follow a normal distribution pattern if one could classify incidents of the same type and with similar levels of severity for the same category.

Linear Regression Models

Liner regression has also been widely used in modeling incident duration, which generally consists of a number of binary variables that represent specific incident characteristics. For example, Giuliano (1989) used three different data sets to develop a statistical model for estimating incident duration based on critical incident characteristics. Due to data limitations, the author developed two separate models: one for all incidents and the other for accidents. In these two models the author used qualitative variables to represent incident types, lane closure, time of a day, accident types, and truck involvement. One of the most significant findings was that the presence of a truck in an accident will significantly increase the total duration of an accident.

Garib et al. (1997) also developed a linear regression model to predict incident duration. Their analysis was based on 205 incidents over a two-month period in Oakland, California. The authors found six significant variables associated with incident duration, which include: number of lanes affected, number of vehicles involved, binary variable for truck involvement, binary variable for time of day, natural logarithm of the police response times, and a binary variable for weather conditions. They concluded that the model with R Square of 0.81 is sufficiently accurate for predicting incident duration.

Conditional Probabilities

Some studies have proposed the use of conditional probabilities for modeling incident duration. For example, control center operators may be interested in the probability of an incident lasting over 30 minutes, after its onset 15 minutes. Most of the previous works have focused on estimating the unconditional probabilities, such as the probability of an incident lasting over 30 minutes.

Jones et al. (1991) proposed a conditional probability model, known as the multivariate statistical model for accident frequency and duration prediction. The authors used the hazard function as the core of the method for estimating the accident duration. Although the accident duration distribution was found to be approximately normal, the authors indicated that the duration data did not perfectly fit the log-logistic distribution. It was also indicated that there is an average 9-minute time lag between the occurrence of an accident and the arrival of response units. The authors defined the accident duration as the time interval between the operator receiving a report of an accident and the time response units leave the scene. Nam and Mannering (2000) followed the same concept by applying hazard-based models developed for biometrics and industrial engineering to predict incident duration.

Time Sequential Models

Khattak (1995) applied the time sequential methodology to predict freeway incident duration. His model includes characteristics associated with incident and operations as key factors, which includes response time, the use of a heavy wrecker, injuries, the number of vehicles involved, and environmental conditions such as the weather and the visibility. Khaattak concluded that most models for incident duration prediction have no operational value since they require knowledge about all incident related variables. The author argued that accident information in actual incident operations is acquired sequentially and this progression should be reflected in the model development.

Decision Trees

Ozbay and Kachroo (1999) used the method of decision trees to predict incident clearance times in the Northern Virginia region. The authors first followed a series of trial prediction methods and received poor results. Their experiments indicate that linear regression techniques generate low R-square values and the duration values do not follow either a lognormal or log-logistic distribution. After determining the independent variables, Ozbay and Kachroo constructed the decision tree. Note that the intended output of the decision tree method is an average duration of similar incidents and the possible range of variation.

2.4. Conclusions

In review of the literature, it becomes clear that statistical methods have been widely used to estimate the duration of non-recurrent congestion in recent decades. Although significant progress has been made by previous studies in the literature; improvements are still necessary. These improvements include the collection of more field data and development of more robust estimation methods. Reliable incident duration, estimated with any effective approach, can serve as the basis for a traffic simulator to optimize the required simulation duration and to assess the resulting traffic impact in a timely manner for real-time operations.

With respect to the use of microscopic simulation for real-time traffic analysis, it has emerged to become a promising technology in recent years, as a result of advances made in computing technologies and its flexibility in representing the actual geometry, driving population, and a variety of system features such as signal control. Therefore, a proper integration of simulation with statistical models will offer an effective and efficient tool for traffic engineers in contending with day-to-day recurrent and non-recurrent congestion.

Chapter 3. System Framework of the Integrated Traffic Simulator

3.1. Principal Functions

The I-95/Route-1 traffic simulator is designed for traffic control operators to manage both recurrent and non-recurrent congestion in the I-95 corridor, between I-495 and I-695. It has three primary functions, which include: incident management, work zone management, and recurrent congestion monitoring.

Incident management

In practice, upon receiving an incident report, the control center operator will immediately dispatch emergency response units (ERU) to the incident site and then estimate potential traffic impacts, such as the evolution of traffic queues, vehicle delays, and speeds during the incident management period. Based on the estimated traffic impacts, control center operators can determine where and how to inform the approaching motorists and evaluate the necessity and effectiveness of implementing any traffic control strategies.

A reliable estimate of traffic impacts, however, is a difficult task to undertake. This process varies with a variety of factors, such as the time-varying approaching traffic volume, geometry of incident sites, incident nature, incident response time, clearance time, and implementation of detour operations or not. The I-95/Route-1 simulator presented in this study is designed to assist traffic operators in performing vital impact assessments during the period of incident management. The embedded traffic simulation module, based on highway design plans and detector data, can offer a reliable prediction of traffic impacts due to incidents. The simulator with its knowledge-base/prediction module can also assist operators in estimating the required incident operating duration that is one of the key factors determining the incident impact on traffic conditions.

Work-zone management

Compared to incident management, work-zone operations generally have longer durations and blocked roadway segments. In practice, prior to work-zone operations, traffic engineers need to assess the potential impacts of each candidate plan with respect to queue length, delay, and average speed. Since traffic patterns may vary over different times of a day, the optimal plan for work-zone operations may also be time-dependent.

The developed I-95/Route-1 simulator offers a convenient and effective way for traffic engineers to evaluate all candidate plans by taking advantage of the up-to-date volume information from on-line detector data.

Recurrent congestion monitoring

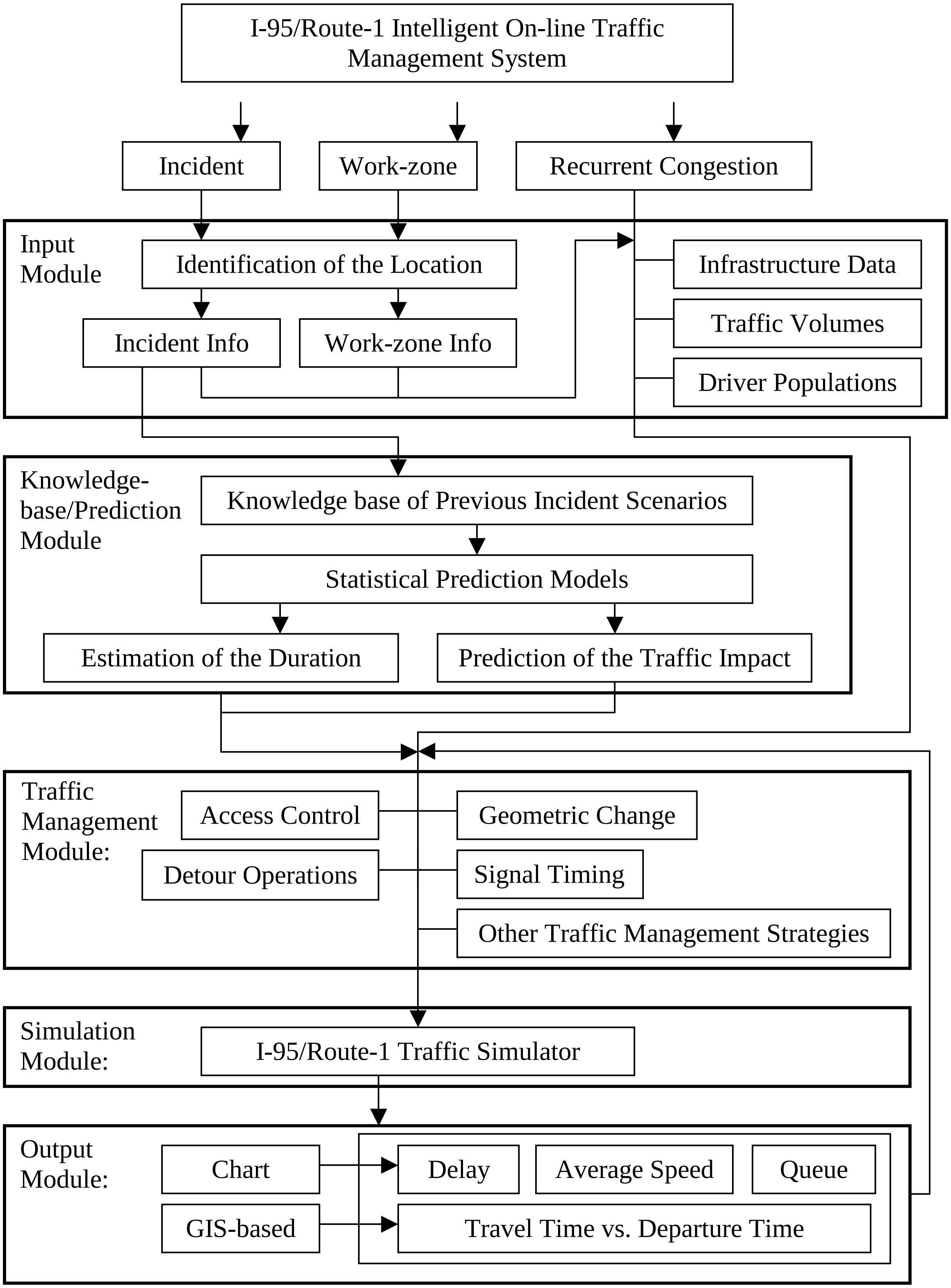
The I-95/Route-1 simulator has been designed with a function to simulate and display day-to-day recurrent congestion using an embedded traffic simulation program and the map-based output. Such information in conjunction with other available traffic reports could serve as the basis for updating traveler information systems.

3.2. Interrelations Between All Principal Modules

As illustrated in Figure 3-1, the developed I-95/Route-1 simulator consists of five principal modules. The main function of each module is briefly stated below:

- The **input module** is designed to assist users in identifying all needed information for the target implementation, and in receiving real-time detector data;
- The **traffic management module** is for evaluating detour operations, controlling the access to ramps, changing the signal timings, and updating the volume information;
- The **simulation module** is for a real-time or off-line projection of the network traffic conditions due to incidents, work-zones, or recurrent congestion;
- The **knowledge-base/prediction module** is developed for inventorying previous incident scenarios, performing preliminary estimate of traffic impacts due to detected incidents, and predicting the duration of a detected incident;
- The **output module** is used for monitoring and assessing the time-varying traffic conditions on target roadway segments, and for comparing the effectiveness of candidate traffic management strategies.

Figure 3-1 Principal modules and their interrelations in the I-95/Route-1 simulator



The operating procedures for the I-95/Route-1 simulator are summarized into the following steps:

Step-1: Specify operation types: incident management, work-zone operation or recurrent congestion monitoring.

Step-2: Identify the location of the traffic event (for incident management and work-zone operations only).

Step-3: Update the available volume for the simulator, based on either available real-time detector data or off-line information.

Step-4: Input detailed information, such as the blocked traffic direction, blocked lanes, and estimated duration of the traffic event.

Step-5: Evaluate available traffic management strategies such as detour operations, changing signal timings, and/or closing ramps.

Step-6: Execute the I-95/Route-1 traffic simulator.

Step-7: Illustrate the outputs based on charts, maps or animations.

Step-8: Change or implement traffic management strategies such as detour operations and then re-executes the I-95/Route-1 traffic simulator.

Step-9: Compare the projected traffic impacts over time on the selected segments using different management strategies.

3.3. Description of The Key Design Principles

All principal functions of the I-95/Route-1 traffic management system have been carefully designed with the following principles in mind.

- ***Take advantage of available on-line and off-line information***

The developed simulator can automatically update its required input information from either on-line or off-line data prior to its execution. The system will also remind the user of any missing information through its input module.

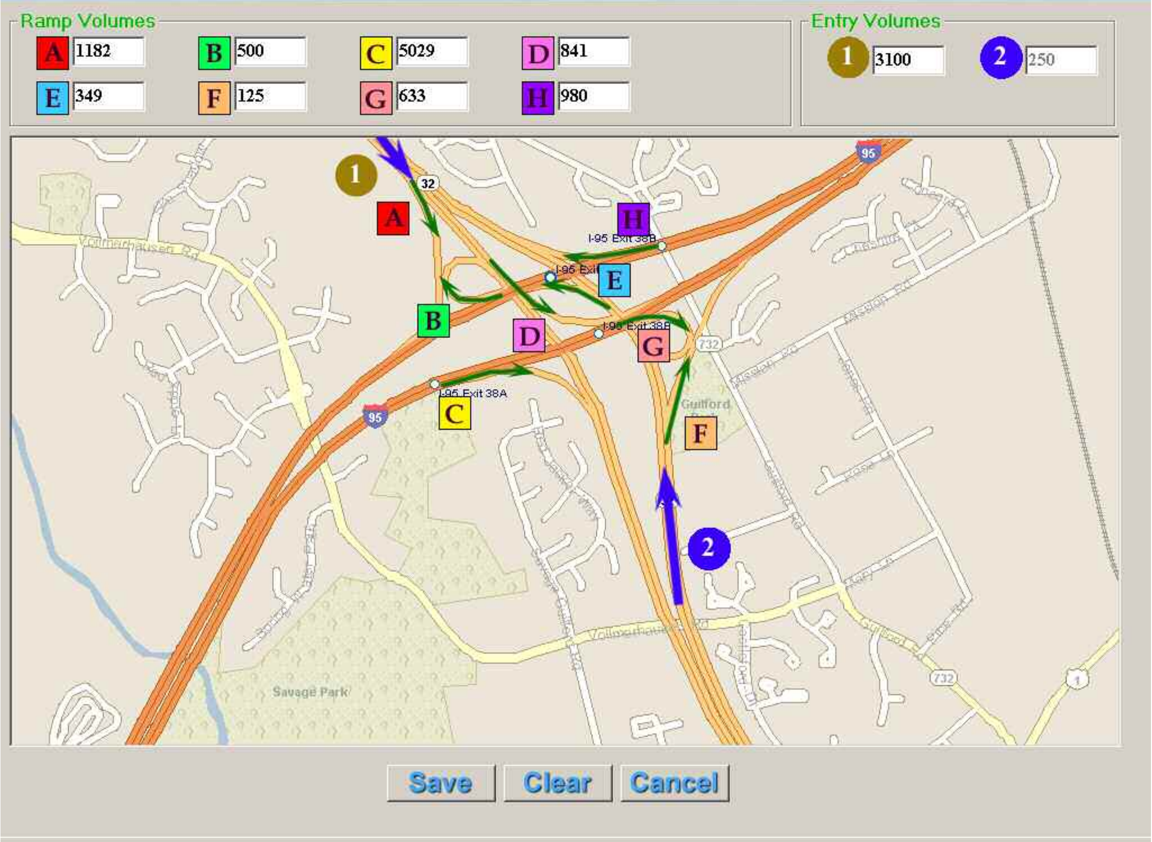
- ***Accuracy of embedded data***

The accuracy of network information embedded in the I-95/Route-1 simulator, such as geometry, signal phases, signal timing, etc., is essential for reliable simulation of actual traffic conditions. The construction of the I-95/Route-1 simulator is based on the actual highway design plans and digital maps of the target area. Satellite photos have also been used for the verification of the geometry.

- ***Automatic data updating and detection of consistency***

The I-95/Route-1 simulator has been carefully designed to integrate the data from both the user and detectors. For example, prior to the execution of the simulation for an incident operation, the system can communicate with the on-line detectors to update all available data. The user can also use the volume update interface, as shown in Figure 3-2, to manually change some entry volumes and/or turning movement percentages. The system will then automatically check the entire data set for its inconsistency prior to execution of simulation. An error message with a detailed description and suggestions for improvement will pop-up on the screen to guide the users if any data inconsistency is detected.

Figure 3-2 The interface for the user to update the volume manually



Input Volumes for Exit 38

Ramp Volumes

A 1182
B 500
C 5029
D 841
E 349
F 125
G 633
H 980

Entry Volumes

1 3100
2 250

- ***Minimizing human-factor related errors***

The simulator has been carefully designed to minimize input errors caused by human factors. For instance, the location of the incident or the work-zone identified in the input module will appear continuously during the input and execution of the simulation. Such a feature will constantly remind the user to review and correct the location information prior to the execution of the simulation.

- ***Minimizing the required input efforts***

To facilitate an effective use of all embedded functions, the simulator is designed with the notion of "replacement of the complex command-language syntax by direct manipulation of the object of interest" (Shneiderman, 1983). As shown in Figure 3-3, the graphic input is more effective in communicating with users than with the text-based design. Note that the left blocked lane in the graphic input refers to the *far right lane* option in the text-based selection because of the direction of the traffic flow.

Figure 3-3 A comparison between graphic input and text-based selection for the lane blockage information in input module

3. How many lanes have been closed?

(Click on the lanes blocked by the accident!)

Graphic input for lane blockage

3. How many lanes have been closed?

(Check the lanes blocked by the accident!)

☐ Far left lane is blocked
☑ Second left lane is blocked
☐ Second right lane is blocked
☑ Far right lane is blocked

Text-based selection for lane blockage

3.4. Key Features Associated with Each Principal Module

The key design features of each principal system module are discussed below:

- ***Input Module***

This module, as shown in Figure 6-3, employs the GIS design concept that enables the user to first identify the approximate location of the freeway segment from the map-view functions. This type of GIS-based design can circumvent the complex input process required by most commercial simulation programs, and minimize the learning time as well as potential input errors. In addition, the input module can automatically integrate data provided by the user with real-time traffic information from traffic sensors.

- ***Knowledge-base Module***

This module is designed to take advantage of information and operational experience accumulated from previous incident management experiences. For example, the Maryland State Highway Administration (MSHA) has kept a detailed response time, incident duration, lane-blockage conditions, incident location and the incident nature for each responded incident. All such incident impact response and management experiences from Year 1997 to Year 2002 are available for constructing the knowledge base. Such information can offer traffic control operators a reliable reference for estimating the potential duration of a detected incident.

- ***Prediction Module***

The prediction module consists of a statistical model and a knowledge-based decision tree for users to estimate the incident duration based on prior operational experience. It also can be used to approximate the maximum possible queue length based on the estimated incident duration. All such information will enable traffic operators to have an immediate assessment of the incident impact on the traffic network prior to execution of the simulation that can take into account real-time approaching traffic volume and other control strategies.

- ***Traffic Management Module***

The traffic module enables users to apply traffic management strategies and/or change control plans of the network through designed interfaces. The user can adopt detour operations, change signal timings, and/or close ramp to identify the most effective traffic management strategy. The user-friendly interfaces provided in this module can also help users to conveniently set up some critical parameters such as the time-varying turning movements based on the desirable detour rate.

- ***Simulation Module***

The core of the I-95/Route-1 traffic simulator is a microscopic simulation program, which has the ability to simulate the evolution of the actual traffic condition under incident management, work-zone operations, or recurrent congestion. The simulation module can also be used to assess the effectiveness of various candidate management strategies. For use in real-time operations, the simulation module is capable of simulating only the sub-network that is likely to be impacted by the detected incident, as opposed to the entire I-95/Route-1 corridor.

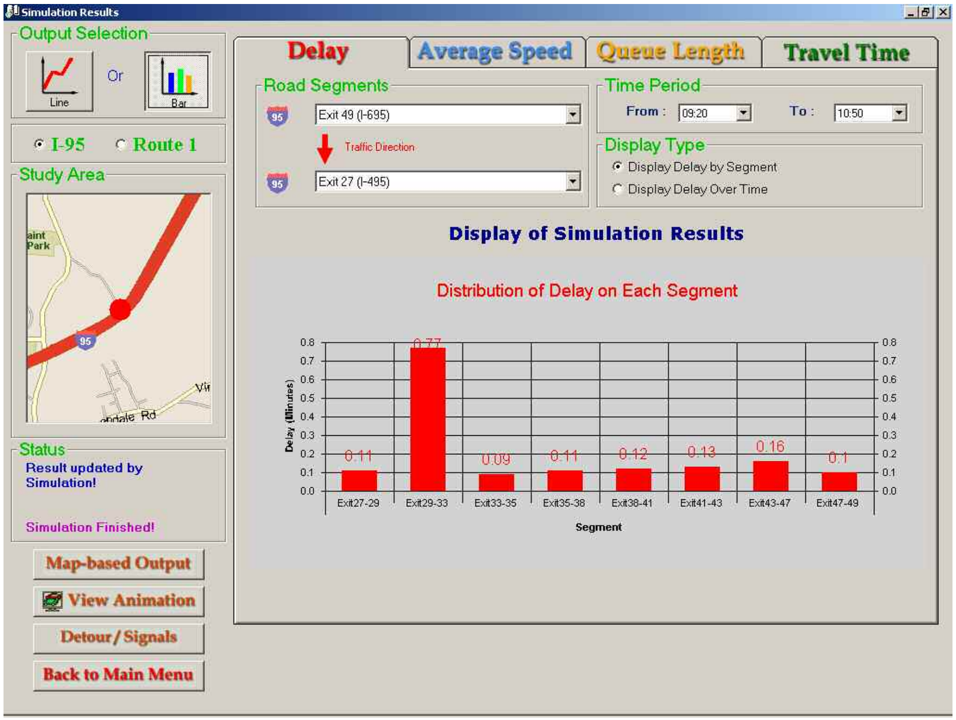
The simulation output is for use in the operational analysis (such as incident response and detour management), and the simulation module has modeled the entire I-95/Route-1 network with the highway design plans that include key geometric features (e.g. vertical and horizontal alignments, the length of deceleration and acceleration lanes, and radius of on- and off- ramps for both freeway network and arterials). Both mainline and ramp traffic volumes over peak and off-peak periods have been calibrated and embedded in the simulator. In addition, the simulator is capable of automatically updating its traffic volume with available on-line detector data.

The current simulator is built using CORSIM – the corridor simulation program developed by FHWA. However, the data sets are sufficiently detailed and comprehensive for use in most existing corridor simulation programs.

- ***Output Module***

With this module, the system operators can choose either to view the animation result from the simulation, or to assess traffic impacts on target segments using pre-formatted statistical charts and/or map views on selected segments over selected time windows. Examples of such outputs are shown in Figure 3-4 and Figure 3-5. Traffic operators can also use the output module to display the interrelation between travel time and departure time for different origin-destination trips.

Figure 3-4 A screenshot of the chart-based output



● I-95 ○ Route 1

Road Segments: Exit 49 (I-695) → Exit 27 (I-495)

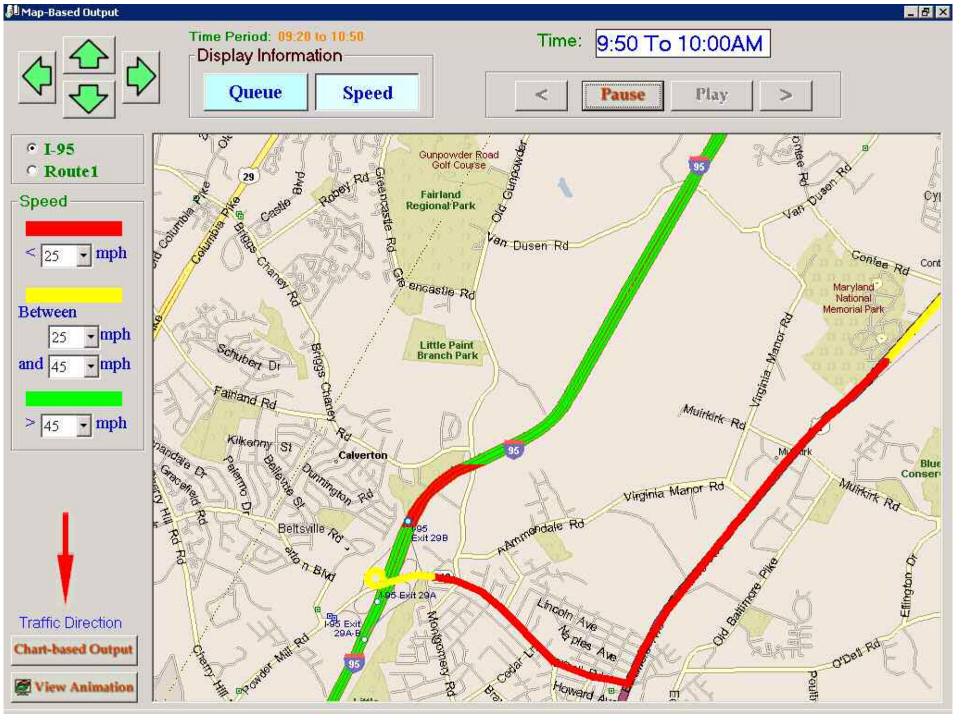
Time Period From: 09:20 To: 10:50

Display Type:
● Display Delay by Segment
○ Display Delay Over Time

Status: Result updated by Simulation!

Simulation Finished!

Figure 3-5 A screenshot of the map-based output



Time Period: 09:20 to 10:50

Time: 9:50 To 10:00AM

● I-95 ○ Route1

Speed:
🟥 < 25 mph
🟨 Between 25 mph and 45 mph
🟩 > 45 mph

3.5. Summary

This chapter has presented the overall framework of the I-95/Route-1 simulator, including the input module, knowledge-base module, prediction module, traffic management module, simulation module and output module. It also identifies the three main functions of the system, which include: incident management, work-zone operation and recurrent congestion monitoring. The interrelation of modules is illustrated, along with an introduction to the operation flow. In addition, some key design principles are introduced and the use of on-line and off-line data, data consistency, human-factor errors, and data accuracy are discussed in detail. Finally, key features of all five modules are presented with figures.

Chapter 4. Principal Functions for Traffic Operations and Management

4.1. Introduction

This chapter presents principal functions of the I-95/Route-1 simulator, which has been designed for traffic operations and management, and includes modeling of network geometric features (e.g. interchanges or intersections), and control functions (e.g. signal phasing, settings, and detouring operations). Also included in this chapter is a detailed discussion of a specially designed function for updating network volumes available only at sample locations through real-time detector data or user input. This function is designed to ensure that users can take advantage of available data to update the information needed for simulation analysis.

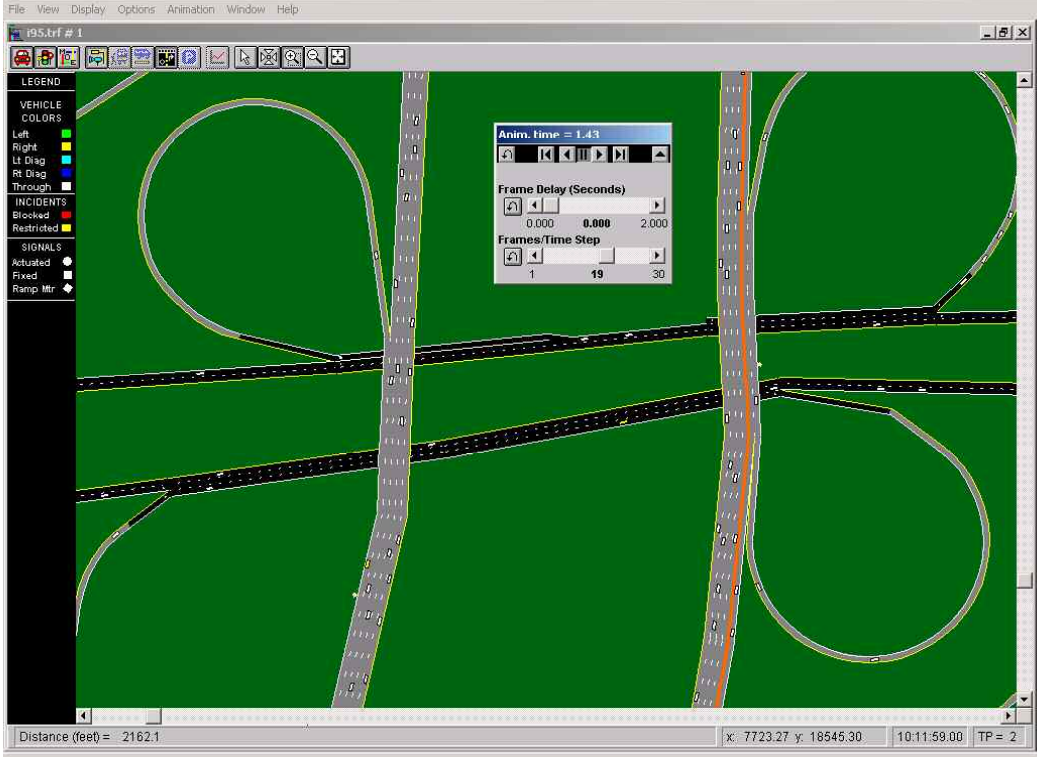
This chapter is organized as follows: a detailed discussion of modeling freeway network features will be presented, including roadway network, traffic signs, and other control functions. This is followed by a description of intersection control and geometry features for simulating local arterials in Section 4.3. A specially designed module for updating time-varying vehicle movements (e.g. volume for the network and turning fractions) is presented in Section 4.4. The information needed to simulate the detour operations and the operating procedures embedded in the simulator are discussed in the last section.

4.2. Modeling of Freeway Network Features

To replicate traffic conditions in a real-world traffic network, the I-95/Route-1 simulator built with CORSIM, is capable of precisely simulating the following key features of a traffic system:

- Road network (in the form of a link-node diagram): including regular lanes, ramps, acceleration/deceleration lanes, and dropped or added lanes.
- Traffic signs: such as speed limit, signs for ramps, signs for congestion and geometric changes, and a variable message system.
- HOV lanes: available on the freeway for specified time periods in the I-95/Route-1 simulator. The carpool vehicles can also be defined using the simulation module to realistically represent the driving population.
- Incidents and temporary events: including incidents and work-zones operations.
- Vehicle types and driving behaviors: for example, the percentage of trucks in traffic and the distribution of driving populations. The simulation module is also capable of capturing different types of driving patterns through its car-following and lane-changing parameters.
- Geometry information: including both vertical and horizontal alignments that can be imported directly from actual highway design plans (see Figure 4-1). A precise modeling of geometry features can ensure the reliability of simulation results. It is particularly useful for identifying potential bottlenecks.

Figure 4-1 An example interchange modeled by the simulation



Anim. time = 1.43

Frame Delay (Seconds) 0.000 **0.000** 2.000

Frames/Time Step 1 **19** 30

Distance (feet) = 2162.1

x: 7723.27 y: 18545.30

10:11:59.00

TP = 2

4.3. Modeling of Intersection Control and Geometry

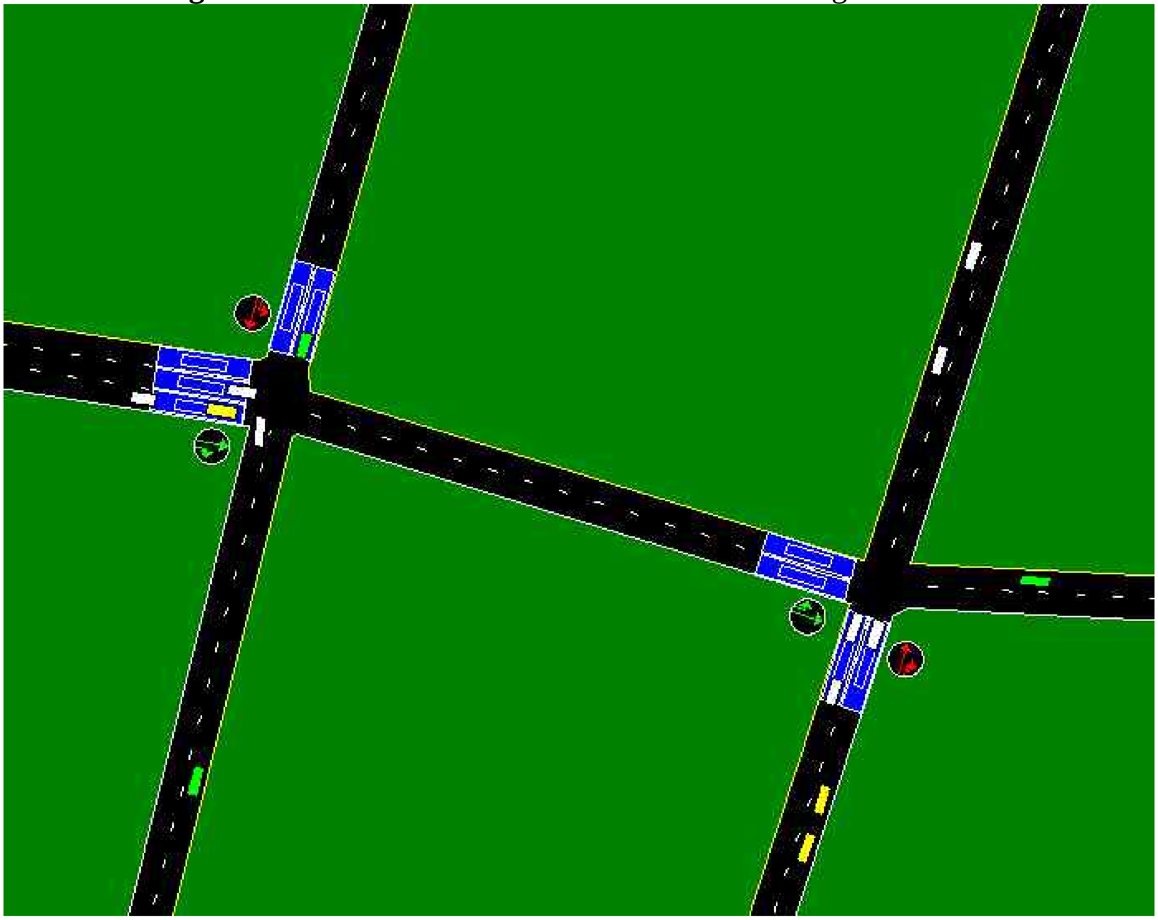
The I-95/Route-1 simulator has modeled all critical functions and features associated with traffic control and/or operations on local arterials, including lane channelizations (such as left-turn only and buses only lanes), intersection approach geometry, stop and yield signs, signal controls, traffic surveillance systems, and queue discharge distribution at intersections. More specifically, the I-95/Route-1 simulator includes the following key features associated with Route-1 and all arterials between these two parallel routes in its network database:

- Lane channelization: includes all kinds of lane channelizations at the intersection, such as protected left turns, right-only turns and bus only lanes.

- Intersection geometry information: including left turn pocket (up to two), right turn only lanes and all types of lane alignment (with up to 5 approaches).
- Signal controls: including both pre-timed signal and actuated signal controls, and interactions between cars and buses. The model for signal control includes signal phases, detector locations, phase parameters such as maximum green time and all red time, as well as signal coordination. The simulator also offers a function for users to change the signal timings in target intersections so as to accommodate the detour traffic.
- Traffic signs: including two-way or four-way stop signs, yield signs, and commonly used warning signs at local arterials.

Figure 4-2 shows an intersection on Route-1 with actuated signal control, locations of detectors indicated with rectangle-boxes and the current signal phases indicated by circles.

Figure 4-2 Intersections on Route-1 with actuated signal controls



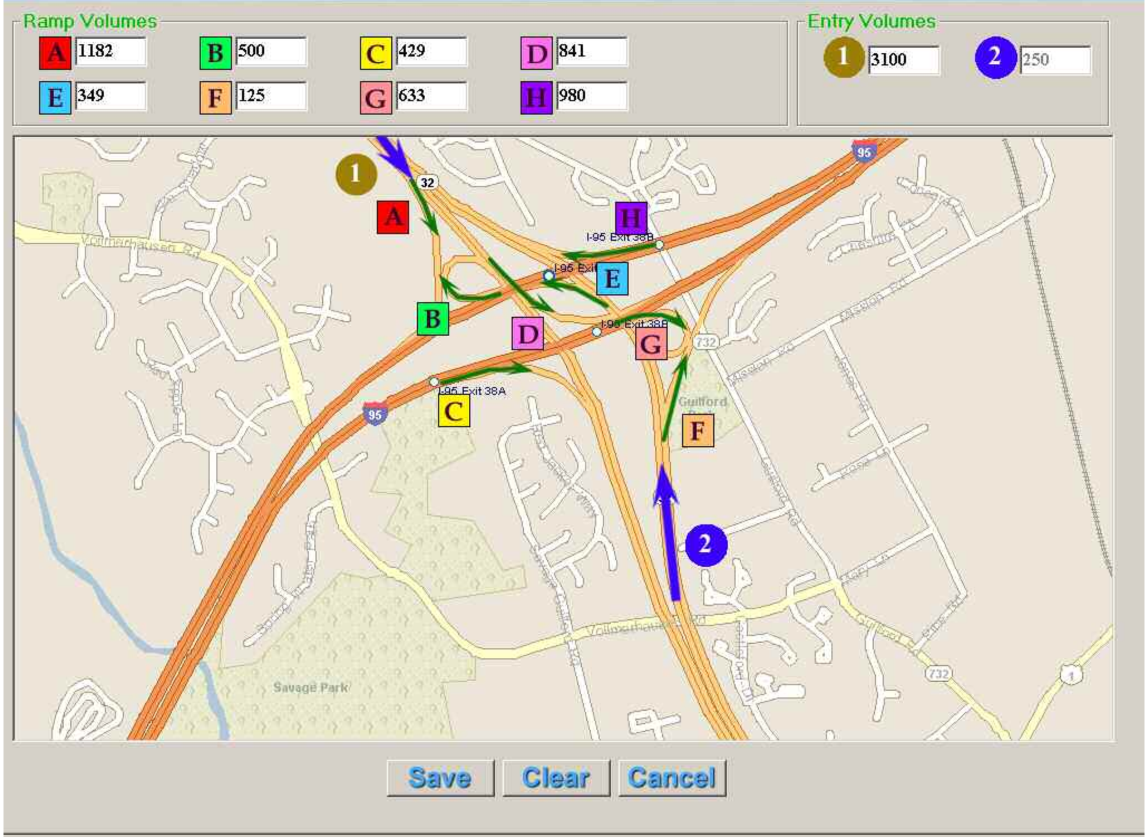
4.4. Modeling of Time-Varying Vehicle Movement

The time-varying vehicle movements discussed in this section include volume on both freeways and arterials, and turning fractions at both intersections and ramps. The variation of volume and turning fractions can be specified at an interval of 10 minutes in the simulation module.

The I-95/Route-1 simulator has been designed with two functions for updating its volumes: automatic update from on-line detectors and manual input by users. With the most update-to-date volume information from detectors, users of the simulator can better project incident impacts in real time and implement necessary management strategies.

Figure 4-3 shows the integrated interface for users to modify the entry volumes as well as the turning fractions.

Figure 4-3 Interface for users to update the entry volumes and turning movements



Input Volumes for Exit 38

Ramp Volumes

A 1182

B 500

C 429

D 841

E 349

F 125

G 633

H 980

Entry Volumes

1 3100

2 250

Given lack of comprehensive surveillance systems, most highway networks can have updated volumes only at some point specific locations. Therefore, the network volume will probably be unbalanced if users only change some of its entry volumes and/or turning fractions from available data. For example, increasing the off-ramp volume may result in unrealistic volumes on some mainline segments due to high downstream off-ramp volumes. To avoid the unrealistic volume distributions resulting from partially available real-time or updated data sets, the I-95/Route-1 simulator has a function for checking the network balance in the input module. The core concept of re-balancing the network volume is to make sure that the off-ramp volumes input from users or detectors does not result in unrealistic mainline volumes. The algorithm embedded in this updating module consists of the following principal steps:

Step 1: If the link is an entry link, B(i) = entry volume, go to Step 4.

Step 2: If the off-ramp volume is updated in the interface, go to Step 3.

Step 3: Set the upstream volumes equal to the downstream volume plus off-ramp volume, A(j, j) = 1, and B(j) = off-ramp volume, go to Step 5.

Step 4: Set A(i, i) = 1, A(j, i) = - (off-ramp split rate), A(k, i) = - (mainline rate).

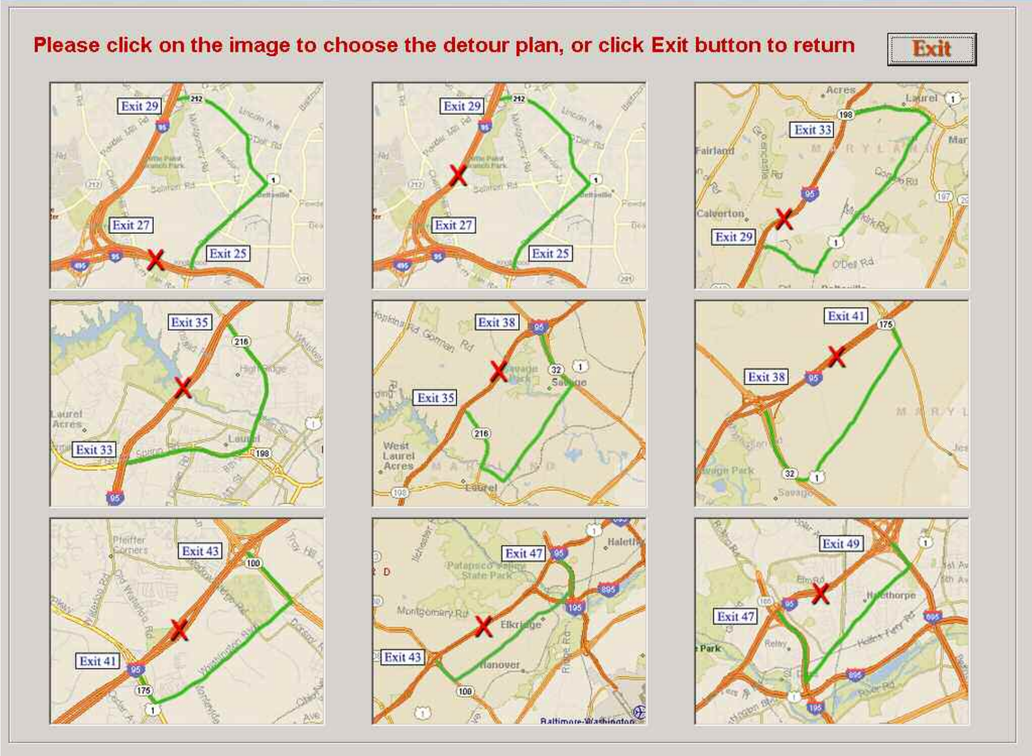
Step 5: Solve AX = B. If X >= 0, the network volume is valid.

where i is the upstream link, j is the off-ramp link, and k is the downstream link.

4.5. Modeling of Detour Operations

Detouring traffic during severe incidents is one of the MDSHA’s most commonly used strategies for contending with non-recurrent congestion. On the I-95/Route-1 commuting corridor, as shown in Figure 4-4, there are a total of 9 detour routes preset by MDSHA for such a need. The simulator can automatically select a recommended detour route based on the incident location and the traffic direction. However, users can always apply other detour routes for their operational needs.

Figure 4-4 9 preset detour routes for I-95/Route-1 by MDSHA



Please click on the image to choose the detour plan, or click Exit button to return

To execute the detour operations, users need to input the following three parameters: start time, detour duration and the percentage of detour volume. To allow the detour traffic to travel on the selected detour route and go back to I-95, the turning fractions on both intersections and ramps must be adjusted accordingly. Note that the adjustments for turning fractions are dynamic in nature, because it may take some time intervals for the detour traffic to arrive at the target intersection from the starting time of detour operations. The simulator has provided a function for automatically updating all the time-varying turning fractions at all ramps and intersections on the detour routes, based on those three parameters input by users. Based on the definition of variables and the assumption that during one time interval the traffic flow speed on one link is constant with the average flow speed from the simulation output, the procedures for automatically updating turning volumes can be summarized as follows:

Step 1: update the turning fractions at the starting time of detour operations for detour traffic to leave the I-95 from off-ramps.

Step 2: calculate the travel time for the detour traffic to arrive each intersection or ramp on the detour route.

Step 3: change the turning fractions at each intersection or ramp based on the estimated arrival time of the detour traffic and detour volume.

Step 4: adjust signal timings at each intersection to accommodate the detouring traffic volume.

Step 5: if detour traffic goes back to I-95, then stop, other wise go to step 2.

The same procedure will be performed again based on the ending time of the detour operation to adjust the turning fractions back to the condition prior to the detour operations.

Chapter 5. Principal Functions for Traffic Impact Prediction

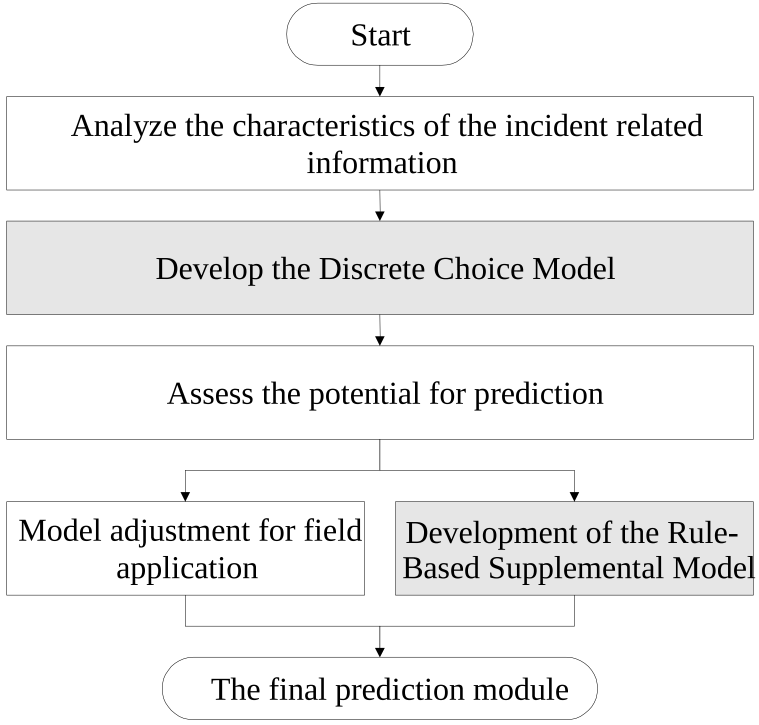
5.1. Introduction

In practice, most congestion management strategies cannot function as effectively as expected without using approximating incident duration. Estimation of the required clearance duration for a detected incident; however, is a challenging task as it varies with a variety of factors, including the nature of incidents, location, number of blocked lanes, severity level of personal injuries, and need of special equipment. This is one of the primary reasons for having only very limited studies on this issue.

Most of the studied approaches presented in the literature for incident prediction are probabilistic in nature, and have made significant contribution towards a better understanding between required incident duration and associated critical factors. However, improvements are still needed to ensure the successful implementation of an incident duration estimation model. Based on the valuable information in the literature, the I-95/Route-1 simulator adopts a prediction module with actual data from MDSHA. The developed module has integrated a discrete choice model with a rule-based supplemental module. The former component is developed in response to the following facts: 1) most traffic center operators would prefer the duration of a detected incident to be estimated in time intervals (e.g., 30-40 minutes), rather than in a precise time frame (e.g. 34, minutes); and 2) a large number of critical factors contributing to the resulting incident duration are discrete in nature or represented with binary indicators.

The supplemental module is designed to capture those severe incidents, which generally belong to a particular category (e.g., fatalities) with their durations determined mainly by one or two critical factors. Inclusion of those severe incident samples in the development of the first component would significantly degrade the prediction quality of the resulting model. Hence, Figure 5-1 illustrates that the prediction module has integrated an advanced statistical model based on operational experience presented rules to illustrate the full strength of both methods for contending with the difficult task of estimating incident duration.

Figure 5-1 The flow chart of the entire System



Chapter 5 is organized as follows: an exploratory analysis of critical variables associated with the incident duration is presented in Section 5.2. This is followed by the construction of a discrete choice model and a rule-based supplemental module in Section 5.3 and Section 5.4, respectively. Conclusions and further research needs are reported in Section 5.5.

5.2. Exploratory Analysis

The data used for the development of the prediction module was obtained from the Maryland CHART (Coordinated Highway Action Response Team) II Database. Beginning in February 2001, CHART adopted a statewide database system to store the information for both traffic conditions and responsive activities. Table 5-1 shows the total number of data in Year 2001 and Year 2002. Only the incident data is used in model development.

Table 5-1 The total number of the data in the CHART II database

Year	Type		Total
	Disabled Vehicles	Incidents	
2001	15,236	8,743	23,979
2002	19,062	13,752	32,814

Since each year contains a sufficient number of data sets, only data from Year 2001 was used for model development. The Year 2002 data is used for assessing the developed model's potential for real-world applications. As observed in the literature review, the following variables may have significant impacts on the required operational duration of a reported incident.

- Incident or accident type
- Number of lanes blocked
- Incident time
- Truck involved
- Number of vehicles involved

- Response time (e.g. travel time to the incident site)
- Weather condition and visibility
- The use of a heavy wrecker

In contrast, the CHART II Database consists of the following information:

- Time Stamps: received time, confirmed time, dispatched time, arrival time, cleared time, and event-closed time
- County name
- Detection Source
- Incident nature
- Lane blockage information
- Incident or disabled vehicle location, including road name, location, and direction
- Type of vehicle involved
- Number of vehicles involved

Based on previous studies and the information in the CHART II database, the following critical incident-related variables have been selected for model development.

Incident Times

Figure 5-2 presents the relationship between response time and the incident duration recorded in the CHART II database, illustrating a positive correlation. Figure 5-3 shows the relationship between incident starting time and incident duration, reflecting that the average duration for those incidents incurred during at night (i.e. from 0:00 to 6:00 and from 21:00 to 23:59) are longer than those occurring during other time periods.

Figure 5-2 The average incident duration for different response time periods

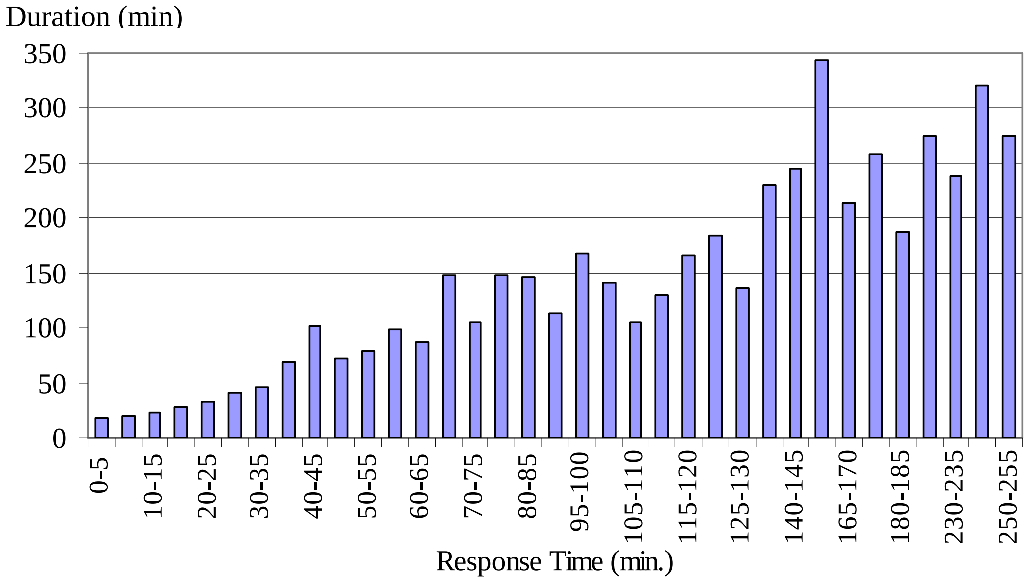
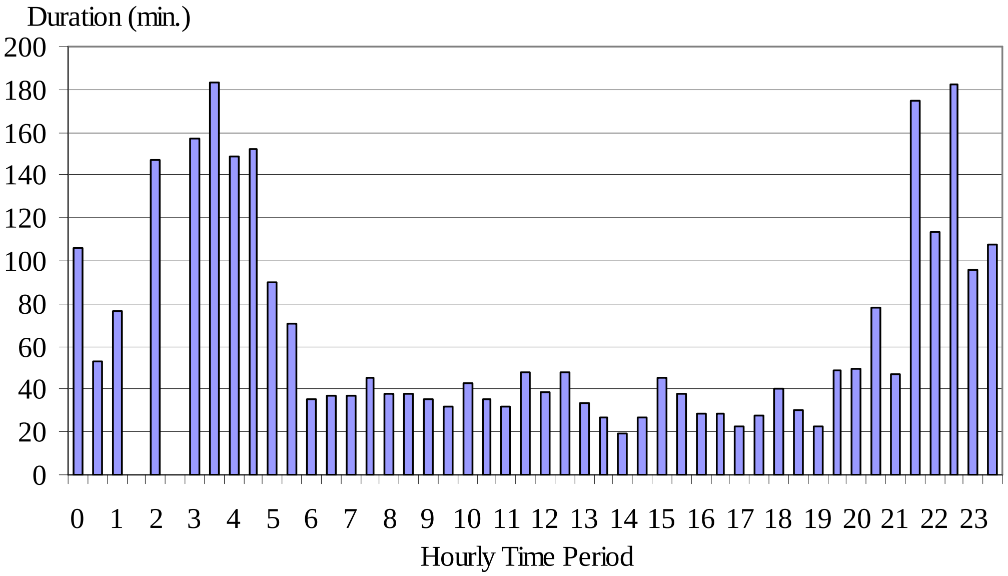


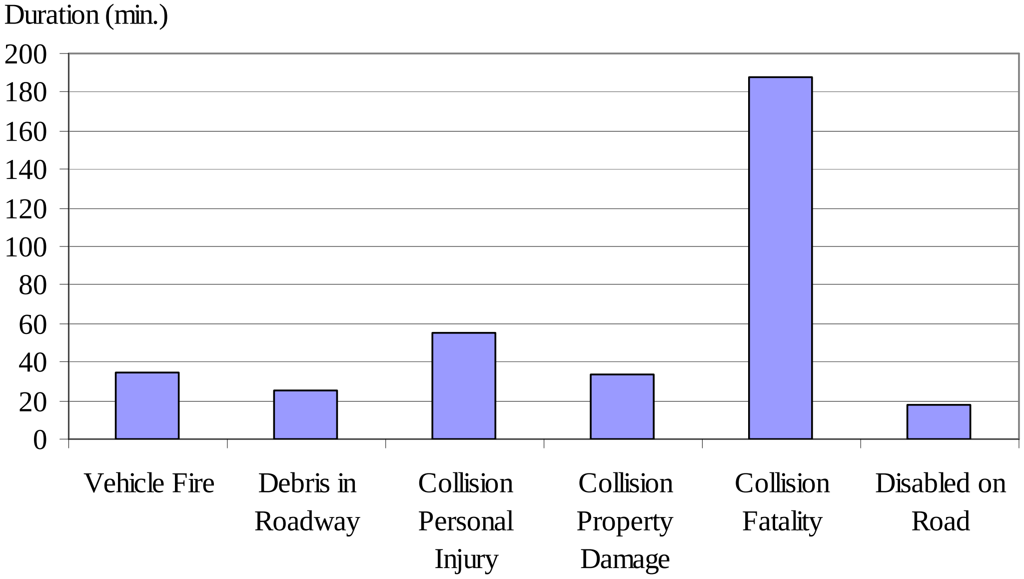
Figure 5-3 The average incident duration for different starting time periods



Incident Nature

Incident nature includes: vehicle fire, debris in the roadway, personal injury, property damage, fatality, and disabled vehicles on the road. Figure 5-4 illustrates the relationship between incident nature and incident duration.

Figure 5-4 The average incident duration for different incident natures

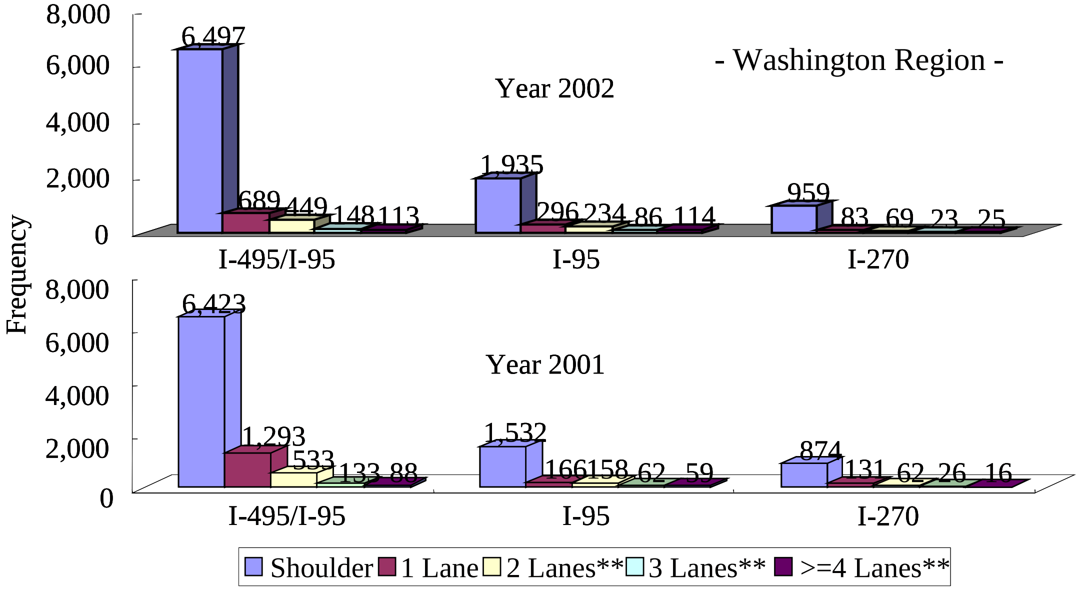


Among all available data, incident nature is one of the most important variables for estimating the required incident duration. For example, Figure 5-4 shows that highway segments experiencing fatalities generally need a significantly longer duration than others for clearance and recovery.

Lane Blockage

Figure 5-5 shows the distribution of incidents and disabled vehicles by lane blockage and road type for the Washington Region. [Note that "shoulder lane blockage" is defined as incidents that result in only shoulder lane blockage].

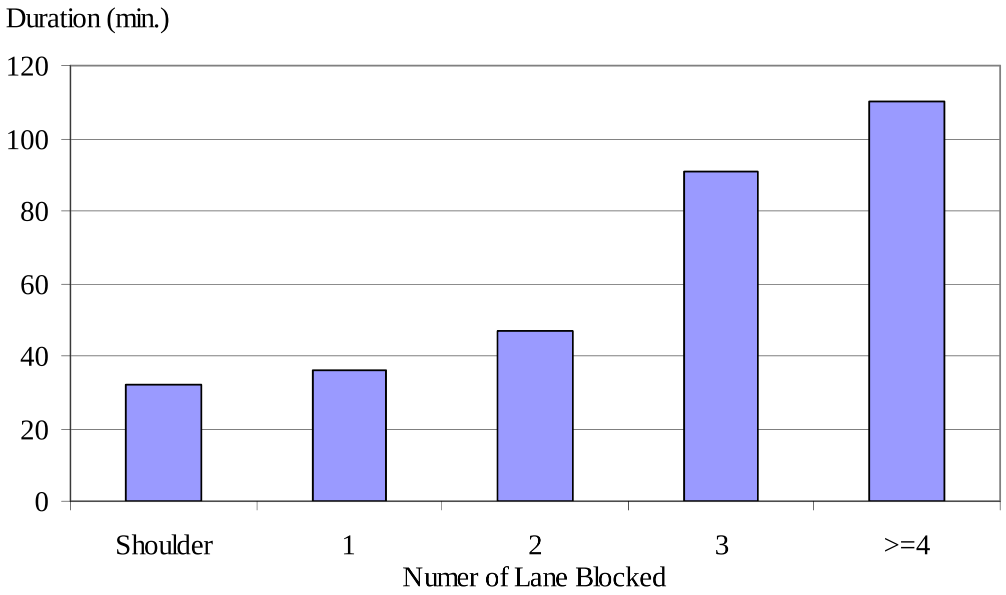
Figure 5-5 The distribution of the incidents and disabled vehicles by lane blockage and road for the Washington region



Note: ** also includes shoulder lane blockages

Figure 5-6 shows the positive correlation between the number of blocked lanes and the duration of the incident.

Figure 5-6 The average incident duration for different numbers of lane blockage



Spatial Distribution of Incidents

The CHART II database also provides the information for analyzing the spatial distribution of incidents along the primary highway system (see Figures 5-7 and 5-8).

Figure 5-7 The distribution of incidents and disabled vehicles by location

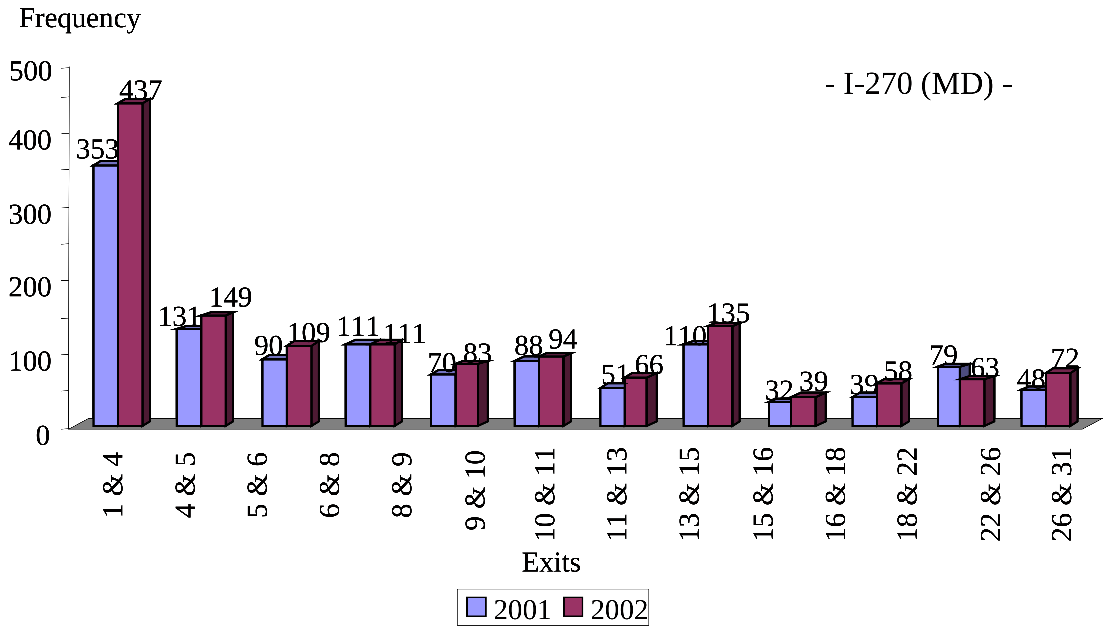


Figure 5-8 The distribution of incidents and disabled vehicles by location

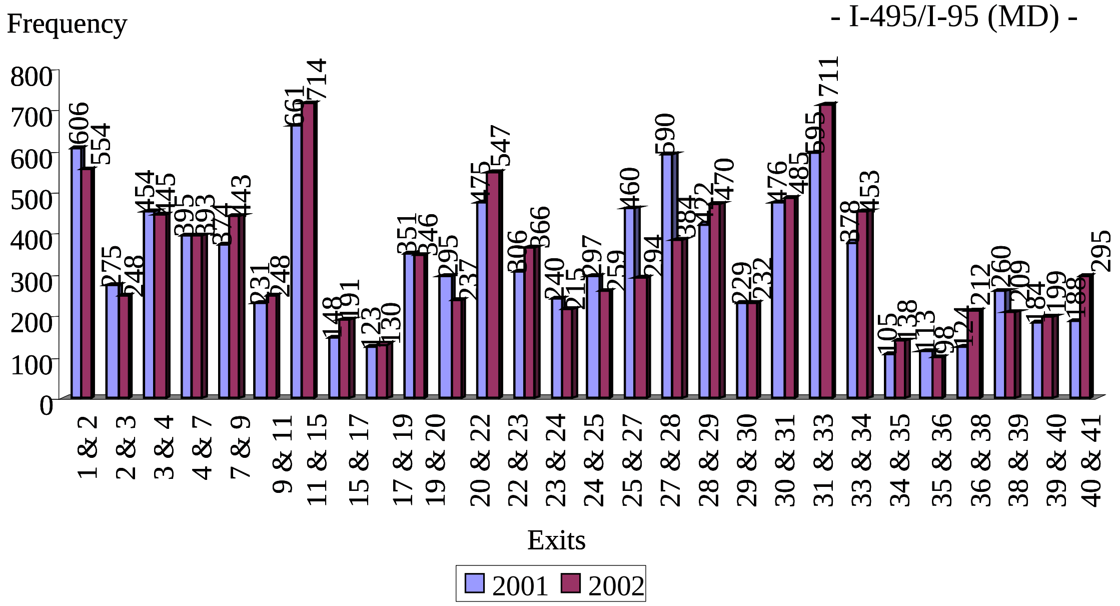
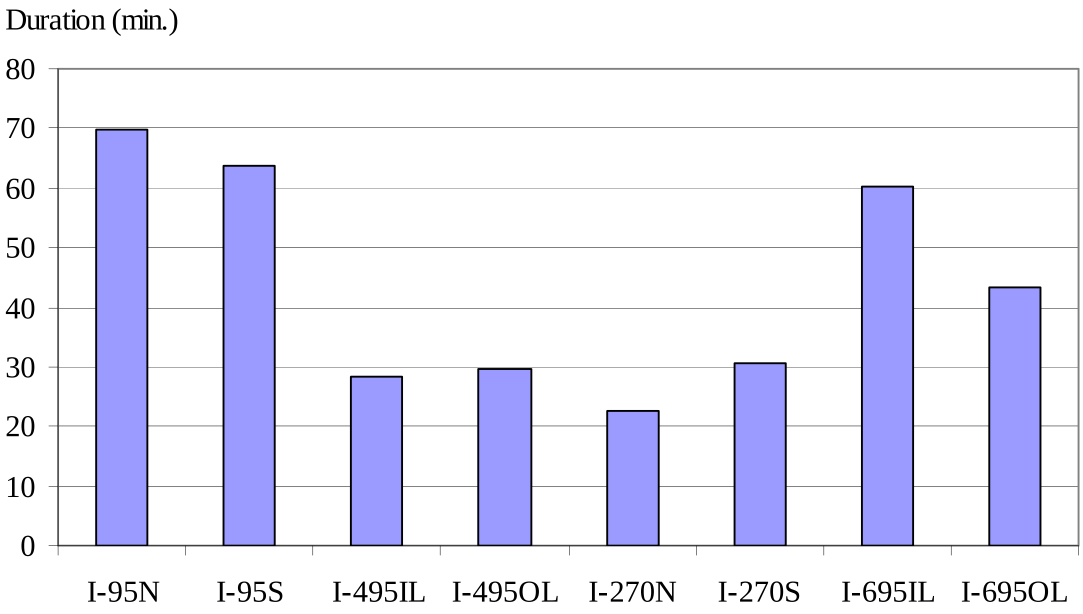


Figure 5-9 illustrates the distribution of average incident durations on different highway systems. The discrepancy in incident duration is partially due to the difference in congestion levels and the distribution of MDSHA's patrol units.

Figure 5-9 The average incident duration for different roads by direction



Incident-related factors used for model development are shown in Table 5-2, and include all critical variables.

Table 5-2 Variables used in the model development

Category	Variable	Notation	Range
Traffic Condition Information	1. Shoulder blockage indicator	SHLDR	0, 1
	2. Number of lane blockage	LB	1, 2, 3, 4
	3. Number of lanes	LN	1, 2, 3, 4
Operation Information	4. MDSHA patrol participant indicator	CHART	0, 1
	5. The response time	RESTIME	> 0
Time Information	6. Weekend indicator	WEEKEND	0, 1
	7. Morning peak-hour indicator (6:00am~9:00am)	AMPEAK	0, 1
	8. Evening peak-hour indicator (4:00pm~7:00pm)	PMPEAK	0, 1
Incident Property Information	9. Number of Vehicles involved	VEHNUM	> 0
	10. Truck involved indicator	TRUCK	0, 1
	11. Tractor-trailer involved indicator	TractorTrailer	0, 1
	12. Vehicle fire indicator	VEHFIRE	0, 1
	13. Collision–property damage indicator	CPD	0, 1
	14. Collision–fatality indicator	CF	0, 1
	15. Collision–personal injury indicator	CPI	0, 1
Roadway Information	16. I-495 Inner Loop indicator	I495IL	0, 1
	17. I-495 Outer Loop indicator	I495OL	0, 1
	18. I-270 North indicator	I270N	0, 1
	19. I-270 South indicator	I270S	0, 1
	20. I-695 Inner Loop indicator	I695IL	0, 1
	21. I-695 Outer Loop indicator	I695OL	0, 1

5.3. The Discrete Choice Model

In developing the discrete choice model, all sample incident durations have been divided into a number of intervals. Each interval is observed in five minutes increments, in an effort to make the process more efficient for control center operators. For example, it may be sufficient for operators to know if the incident duration is within a time period of 30 to 35 minutes, rather than 38.5 minutes. Since all sample incident durations for model estimation were classified into discrete intervals in an ascending order, the Ordered Probit Model offers a uniquely effective way for model calibration.

The Ordered Probit Model is grounded on the following latent regression:

$y^* = \beta' x + \varepsilon$

where y^* is unobserved. What can be observed is:

$y = 1$ if $y^* <= 0$
$= 2$ if $0 < y^* <= \mu_1$
$= 3$ if $\mu_1 < y^* <= \mu_2$
…
$= N$ if $\mu_{N-2} < y^*$

where μ_i are unknown parameters to be estimated with β

Prob $(y=1) = \text{cnorm}\ (0-\beta' x) – 0$
Prob $(y=2) = \text{cnorm}\ (\mu_1-\beta' x) – \text{cnorm}\ (0-\beta' x)$
…
Prob $(y=N) = \text{cnorm}\ (\mu_{N-1}-\beta' x) – \text{cnorm}\ (_{N-2}-\beta' x)$

One can construct the log-likelihood function and compute its derivatives using standard methods. The interval with the highest probability is selected as the most likely interval for the incident duration. A detailed description of the Ordered Probit Model is available in the literature (Greene, 2000).

To be consistent with previous practices for model estimation, this study has divided all incident duration data into 24 categories at an increment of 5 minutes. For example, Category 0 contains sample cases having durations of 0-5 minutes, and Category 1 includes cases lasting between 5 to 10 minutes. With respect to severe incidents lasting more than 2 hours, it is not possible to estimate their duration as the resulting clearance times may vary based on a number of non-technical factors (e.g. institutional barriers and required special equipments). Therefore, severe incidents are grouped into the last category (i.e. Category 24). In addition to the variables mentioned above, the following interaction terms were used in the development of the model:

- X1 – (SHLDR + LB) / LN
- Y1 – I95N * AMPEAK
- Y2 – I95S * AMPEAK
- Y3 – I495IL * AMPEAK
- Y4 – I495OL * AMPEAK
- Y5 – I270N * AMPEAK
- Y6 – I270S * AMPEAK
- Y7 – I695IL * AMPEAK
- Y8 – I695OL * AMPEAK
- Z1 – I95N * PMPEAK
- Z2 – I95S * PMPEAK
- Z3 – I495IL * PMPEAK
- Z4 – I495OL * PMPEAK
- Z5 – I270N * PMPEAK
- Z6 – I270S * PMPEAK
- Z7 – I695IL * PMPEAK
- Z8 – I695OL * PMPEAK

The variable X1 is the ratio between the number of lane blocked (including shoulder lane blockage) and the total number of travel lanes. The terms *Yi* and *Zi* are the interaction variables used to indicate the primary highways for different peak periods, because both traffic conditions and incident duration on commuting corridors vary significantly with the direction of traffic flow and times of a day. The initial Ordered Probit Model estimated with the Year 2001 data is illustrated in Table 5-3. The number of data points for Year 2001, with complete information, is 770 for model estimation.

Table 5-3 The initial ordered probit model estimated with the Year 2001 data

Data Points	770 (from CHART II Database in year 2001)		
Parameter	Estimate	t-statistic	P-value
C	**1.69600**	**4.18853**	[.000]
SHLDR	**-.256916**	**-1.77127**	[.077]
LB	-.032577	-.268495	[.788]
LN	.070111	.748545	[.454]
X1	**.709126**	**1.71953**	[.086]
CHART	**-1.01701**	**-4.22810**	[.000]
RESTIME	**.059333**	**21.1407**	[.000]
WEEKEND	**.344751**	**1.68435**	[.092]
AMPEAK	-.034086	-.183805	[.854]
PMPEAK	-.153726	-.786781	[.431]
VEHNUM	-.017955	-.435492	[.663]
PICKUPVAN	.104810	1.08078	[.280]
TRUCK	**.436106**	**3.82967**	[.000]
TRACTORTRAILERS	**.280141**	**2.26792**	[.023]
DEBRIS	-.409461	-.999010	[.318]
VEHFIRE	**.459718**	**2.06240**	[.039]
CPD	**.279037**	**2.40952**	[.016]
CF	**2.14521**	**5.02067**	[.000]
CPI	**.813981**	**6.31518**	[.000]
I95N	.306017	.935970	[.349]
I95S	**.439708**	**1.53045**	[.126]
I495IL	**-.501027**	**-2.89683**	[.004]
I495OL	**-.370249**	**-2.09346**	[.036]
I270N	**-.691557**	**-1.45203**	[.146]
I270S	.283559	.390291	[.696]
I695IL	**.495027**	**1.92128**	[.055]
I695OL	.053265	.216450	[.829]
Y1	.331240	.545620	[.585]
Y2	**-.923622**	**-1.76800**	[.077]
Y3	.620578E-02	.022411	[.982]
Y4	-.051456	-.194561	[.846]
Y5	-.260716	-.339165	[.734]
Y6	-.456714	-.577245	[.564]
Y7	-.479147	-1.29044	[.197]
Y8	-.028204	-.078782	[.937]
Z1	-.361687	-.662093	[.508]
Z2	-.522649	-.874901	[.382]
Z3	.224969	.879240	[.379]
Z4	.017880	.066888	[.947]
Z5	.571017	1.00177	[.316]
Z6	-.126043	-.147841	[.882]
Z7	-1.66375	-1.96619	[.049]
Z8	.982291	1.27795	[.201]

Note: the number of data points used in this model is 770.

After performing the standard procedures for variable selection, the incident duration model has been finalized, and the results are presented in Table 5-4. The implications of the estimated results by category are discussed below.

Table 5-4 The final ordered probit model estimated with the Year 2001 data

Data Points	770 (from CHART II Database in year 2001)		
Parameter	Estimate	t-statistic	P-value
C	1.87822	7.3866	[.000]
SHLDR	-.19712	-2.1364	[.033]
X1	.56403	4.2109	[.000]
CHART	-.98747	-4.2639	[.000]
RESTIME	.05870	21.3168	[.000]
WEEKEND	.49032	2.6455	[.008]
TRUCK	.40631	3.6691	[.000]
TRACTORTRAILERS	.28265	2.3754	[.018]
VEHFIRE	.54871	2.5072	[.012]
CPD	.26205	2.5165	[.012]
CF	1.97082	4.7246	[.000]
CPI	.82413	7.2073	[.000]
I495IL	-.44350	-4.5176	[.000]
I495OL	-.39520	-3.9596	[.000]
I270N	-.44709	-1.9410	[.052]
Z7	-1.38157	-1.7318	[.083]

Traffic Condition Information

The negative coefficient of the shoulder blockage indicator (SHLDR) indicates that the required duration for an incident will be shorter if the shoulder roadway is not blocked. As estimated, the coefficient for the ratio between the number of blocked lanes (including shoulder lane blockage) and the total number of travel lanes (X1) is positive.

Operations Information

The negative coefficient of the MDSHA patrol indicator (CHART) shows that the incident duration generally decreases when MDSHA incident response units are used. This is consistent with previous CHART evaluation results (Chang, Point-du-Jour, J. Y., 2003). The response time (RESTIME) is the time period between receiving the report of an incident and the arrival of response units on the scene. This may vary with the distance between the operation center and the incident, traffic conditions, and the availability of required equipment. As expected, the results show that a longer response time will result in a longer incident duration.

Time Information

In this category the weekend indicator (WEEKEND) is a significant positive coefficient because of fewer patrols from CHART during the weekend. Both peak hour variables (AMPEAK and PMPEAK) are not significant, except those interaction terms used to capture roadway conditions under different peak-periods.

Incident Nature Information

Both truck (TRUCK) and tractor-trailer (TRACTORTRAILER) indicators are positively significant. Incidents involving trucks or tractor-trailers are generally more severe and require longer clearance time. In addition, incidents that result in vehicle fires, property damage, fatalities, and personal injuries all require longer durations as evidenced by their positive coefficients.

Road Information

The road indicators listed are for primary and congested commuting corridors. In the final model, those indicators for the I-495 inner loop (I495IL), I-495 outer loop (I495OL), I-270 northbound (I270N), and the interaction term for I-695 inner loop during the evening peak period (Z7) all exhibit significantly negative coefficients. These results indicate that incidents on these major highways generally take a shorter duration than the same type of incidents on other highways. This is a result of MDSHA placing more highway patrol units on the primary commuting highways.

To assess the potential of using the estimated model for prediction, the sample incident duration data for convenience of presentation is separated into four groups: 0~30 minutes, 30~60 minutes, 0~60 minutes, and over 60 minutes. Table 5-5 shows the estimation results with the Year 2001 data.

Table 5-5 The estimation result of the Year 2001 data

Estimated Error	±5 min			±10 min		
Incident Duration	Correct Estimation	Under Estimation	Over Estimation	Correct Estimation	Under Estimation	Over Estimation
0 ~ 30 min	73.21%	5.58%	21.21%	93.97%	0.67%	5.36%
30 ~ 60 min	44.57%	40.76%	14.67%	61.96%	28.26%	9.78%
0 ~ 60 min	64.87%	15.82%	19.30%	84.65%	8.70%	6.65%
Over 60 min	34.06%	–	–	36.96%	–	–

Table 5-5 shows that using the difference of 10 minutes as an acceptable range for management and impact assessment allows the estimated model to achieve the correct estimation of 93.97%, 61.96%, and 36.96%, for incidents with a duration of 0~30 minutes, 30~60 minutes, and larger than 60 minutes. It also suggests that the discrete model developed for the prediction module offers reasonably reliable estimates for those incidents with durations less than 60 minutes (about 84.65%). For severe incidents taking more than one hour, estimation of their duration is neither meaningful nor possible, as the resulting clearance time may vary with a variety of non-technical factors (e.g. institutional barriers and required special equipment).

The cases with incident durations between 30 to 60 minutes, the percentage of the underestimated cases is about 28.26%. From an operations perspective, the predicted traffic impact will also be underestimated if the incident duration is underestimated. Therefore, the cases with incident durations between 30 to 60 minutes need to be adjusted systematically with a constant based on information in the knowledge base to decrease the percentage of underestimated cases. Table 5-6 illustrates the estimated results compared with the actual year 2002 data after placing different adjustment factors to all incidents that lasted between 30-60 minutes.

Table 5-6 The estimation results compared with the Year 2002 data

Estimated Error	±5 min			±10 min		
Adjust Interval	Correct Estimation	Under Estimation	Over Estimation	Correct Estimation	Under Estimation	Over Estimation
+0	28.57%	63.67%	7.76%	44.08%	50.61%	5.31%
+1	35.51%	51.84%	12.65%	52.65%	39.59%	7.76%
+2	41.63%	39.59%	18.78%	64.49%	22.86%	12.65%
+3	**43.67%**	**22.86%**	**33.47%**	**67.76%**	**13.47%**	**18.78%**
+4	39.18%	13.47%	47.35%	60.82%	5.71%	33.47%
+5	33.88%	5.71%	60.41%	49.80%	2.86%	47.35%

As shown in Table 5-6, after adjustments, the “+3” interval estimation result (15 minutes) has the higher percentage of correct estimation and less percentage of under estimation. Table 5-7 shows the estimation results with the Year 2002 incident data after adding adjustment terms for those incidents with durations between 30 to 60 minutes. The number of available data points for comparison is 905.

Table 5-7 The prediction results compared to the actual incident duration in Year 2002

Estimated Error	±5 min			±10 min		
Incident Duration	Correct Estimation	Under Estimation	Over Estimation	Correct Estimation	Under Estimation	Over Estimation
0 ~ 30 min	70.39%	6.27%	23.33%	89.22%	1.57%	9.22%
30 ~ 60 min	43.67%	22.86%	33.47%	67.76%	13.47%	18.78%
0 ~ 60 min	61.72%	11.66%	26.62%	82.25%	5.43%	12.32%

As shown in Table 5-7, when using the 10-minute acceptable interval the developed model can estimate incidents of 0~30 minutes and 30~60 minutes at an accuracy level of 89.22% and 67.76%, respectively. The percentage of underestimated cases decreased to 13.47%. Overall, the accuracy for cases with incident durations less than 60 minutes is 82.25%.

From the results in Tables 5-5 and 5-7, it is clear that the developed discrete model is sufficiently reliable for those incidents with durations less than one hour, and the response procedures are more likely to be standardized. However, for severe incidents with durations longer than one hour, it is difficult to estimate their durations within a reliable range. Some of the severe incidents belong to particular categories; however, they can be approximated to a degree using general rules developed from previous operational data.

5.4. The Rule-Based Supplemental Module

The ordered probit model does not completely capture all factors and the complex interactions that may affect incident duration. As a result, a rule-based supplemental module has been developed for estimating the duration of particular types of severe incidents. The rule-based supplemental module was constructed based on the same Year 2001 and Year 2002 data from the CHART II database; however, more samples were used as the rule-based module does not require all information needed in the discrete model. A total of 1,104 sample incidents were used to identify rules for developing this supplemental module. The constructing procedures for the rule-based supplemental module are summarized in the steps below:

Step 1: Classify sample incident durations based on the following information:

- Incident nature
- Peak hour indicator
- Number of vehicles involved
- Truck indicator
- Tractor-trailer indicator
- Weekday indicator
- Number of lanes closed
- Response time

Step 2: Group incidents based on the above classifications and established rules.

Step 3: Compute applicable ranges for each rule to estimate the incident duration, based on available cases in each group.

For example, the incident nature is set as the first layer for the rule-based decision tree, and peak-hour indicator is adopted as the second layer in the decision tree. Other variables are also used in constructing the rule-based module. Table 5-8 illustrates the developed rules and their performance. Rules are only constructed for the following incident types: Disabled on Road, Collision/Fatality and Collision/Property Damage.

Table 5-8 Available rules and their performances

No.	Rule	Correct Est.	Total cases
1	IF Nature = Disabled on Road AND Response Time > 60 minutes THEN 60 minutes < Incident Duration < 90 minutes	85.7%	7
2	IF Nature = Disabled on Road AND Response Time < 60 minutes THEN Incident Duration < 60 minutes	98.1%	641
3	IF Nature = Collision, Fatality AND in Peak Hours AND (Truck Involved OR Tractor Trailers Involved OR Pick/Van Involved) THEN Incident Duration > 3 hours	100%	8
4	IF Nature = Collision, Fatality AND Not in Peak Hours AND in Weekdays AND 1 vehicle involved Then Incident Duration > 140 minutes	100%	6
5	IF Nature = Collision, Fatality AND Not in Peak Hours AND in Weekdays AND 2 vehicles involved Then Incident Duration > 145 minutes	70%	10
6	IF Nature = Collision, Fatality AND Not in Peak Hours AND in Weekdays AND 3 or more vehicle involved Then Incident Duration > 3 hours	100%	6
7	IF Nature = Collision, Fatality AND Not in Peak Hours AND Not in Weekdays AND 2 or more vehicles involved Then Incident Duration > 160 minutes	90%	10

8	IF Nature = Collision, Property Damage AND in Peak Hours AND 1 vehicle involved AND Truck Involved AND 2 or less lanes closed THEN 60 minutes < Incident Duration < 100 minutes	100%	3
9	IF Nature = Collision, Property Damage AND in Peak Hours AND 2 or more vehicles Involved Response Time > 60 minutes THEN 90 minutes < Incident Duration < 120 minutes	83.3%	6
10	IF Nature = Collision, Property Damage AND Not in Peak Hours AND Response Time > 60 minutes AND Tractor Trailer Involved THEN Incident Duration > 160 minutes	75%	12
11	IF Nature = Collision, Property Damage AND Not in Peak Hours AND Response Time > 60 minutes AND No Tractor Trailer Involved THEN 70 minutes < Incident Duration < 120 minutes	100%	6

Although the rule-based approach seems to offer a reasonable approximation for previously identified types of severe incidents, it is difficult to capture the patterns of other severe incident scenarios (e.g. Vehicle Fire, Debris on Roadways) based on currently available data. In addition, no rule can be established for Collision incidents that result in Personal Injury. Table 5-9 illustrates the set of scenarios that require additional data for possible development of more effective rules.

Table 5-9 Scenarios that cannot be observed by rules

No.	Scenario	Total cases
1	Nature = Collision, Fatality AND in Peak Hours AND Not Truck Involved AND Not Tractor Trailers Involved AND Not Pick/Van Involved	8
2	Nature = Collision, Fatality AND Not in Peak Hours AND Not in Weekdays AND 1 vehicle involved	6
3	Nature = Collision, Property Damage AND in Peak Hours AND 1 vehicle involved AND Truck Involved AND 3 or more lanes closed	1
4	Nature = Collision, Property Damage AND in Peak Hours AND 1 vehicle Involved AND No Truck Involved AND (8 out of 56 cases with duration more than 60 minutes)	56
5	Nature = Collision, Property Damage AND in Peak Hours AND 2 or more vehicles Involved AND Response Time > 60 minutes (15 out of 317 cases with duration more than 60 minutes)	317
6	Nature = Collision, Property Damage AND Not in Peak Hours AND Response Time < 60 minutes AND (47 out of 414 cases with duration more than 60 minutes)	414
7	Nature = Vehicle Fire	20
8	Nature = Collision, Personal Injury	224
9	Nature = Debris on Roadway	26

5.5. Summary and Conclusions

This chapter has presented principal prediction functions for the I-95/Route-1 simulator that estimates the duration of a detected incident. A discrete choice model was developed using 2001 incident data from MDSHA for estimating the incident duration.

The model performance test was performed using Year 2002 incident data. The preliminary evaluation results indicate that the discrete model is sufficiently reliable for estimating incidents that have durations less than 60 minutes. For severe incidents that last more than one hour, a rule-based supplemental module has been developed to approximate their durations, but not all scenarios can be covered by these rules.

Chapter 6. Principal Interface Functions

6.1. Introduction

This chapter highlights the key features of the interface function for each principal module of the I-95/Route-1 simulator. The design of the interface is based on the following principles:

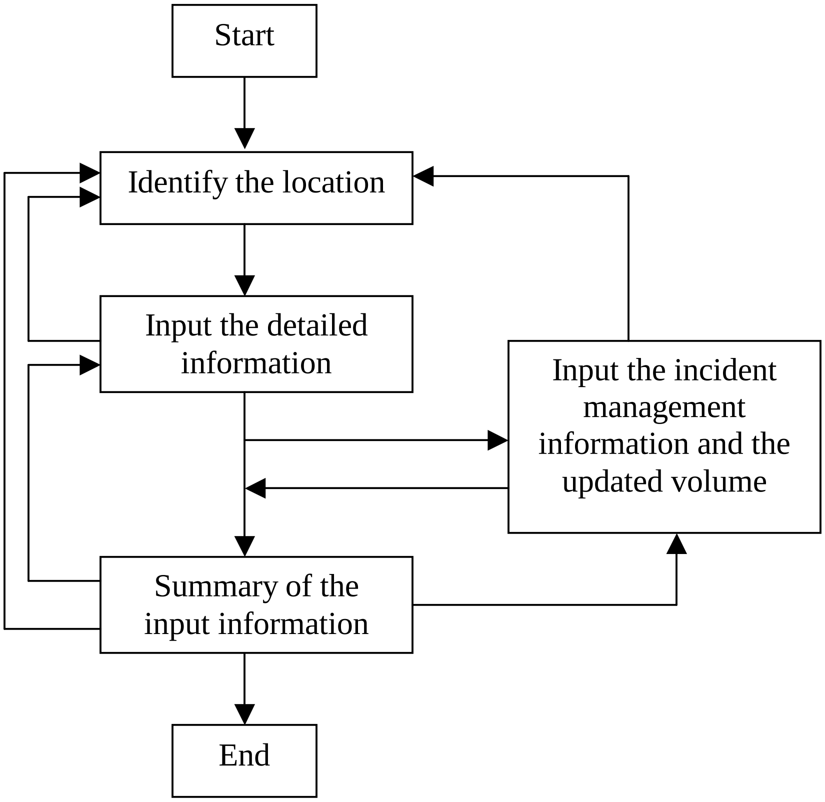
1. Minimizing the required input efforts
2. Minimizing human-factor related errors
3. Automatic data updating and detection of consistency

A detailed description of the input interface functions is presented in the first section, which includes location identification, required input information, volume update, ramp access control, detour operations, and signal timings. This section is followed by a detailed discussion on the principal output interface features designed to allow users to take advantage of information generated from the results of simulation in section 6.3. Recommendations for enhancements of the existing design, in response to advances in computing technologies, are presented in the last section.

6.2. Interface for Input Module

The input module is designed to receive all data needed to simulate the target applications, including incident management, work-zone operations, and recurrent congestion monitoring (see Figure 6-1). A list of essential data for these three primary applications is listed below:

Figure 6-1 The operational structure of the input procedures



- Incident management
    - The location of the incident
    - The direction of the traffic blocked by the incident
    - The lane blockage information
    - The onset time and the estimated duration of the detected incident
    - The duration of the simulation
    - Any available updated volume
- Work-zone operations
    - The location of the incident
    - The direction of traffic blocked by the work-zone operations

    - Precise location of the work-zone
    - The length of the work-zone
    - The lane blockage information
    - The starting time and the duration of the simulation
- Recurrent congestion monitoring
    - The target traffic direction
    - The start time and the duration of the simulation
    - Any available updated volume

With the incident management application, the simulation duration should be set to an interval longer than the actual incident clearance time to capture all traffic impacts. However, users can change to a shorter duration to observe the traffic condition after the onset of a detected incident. Only optional information, such as volume updates from user input or on-line detector data, can be ignored if not available. Users can execute the simulator based on its embedded default volume.

Location Identification

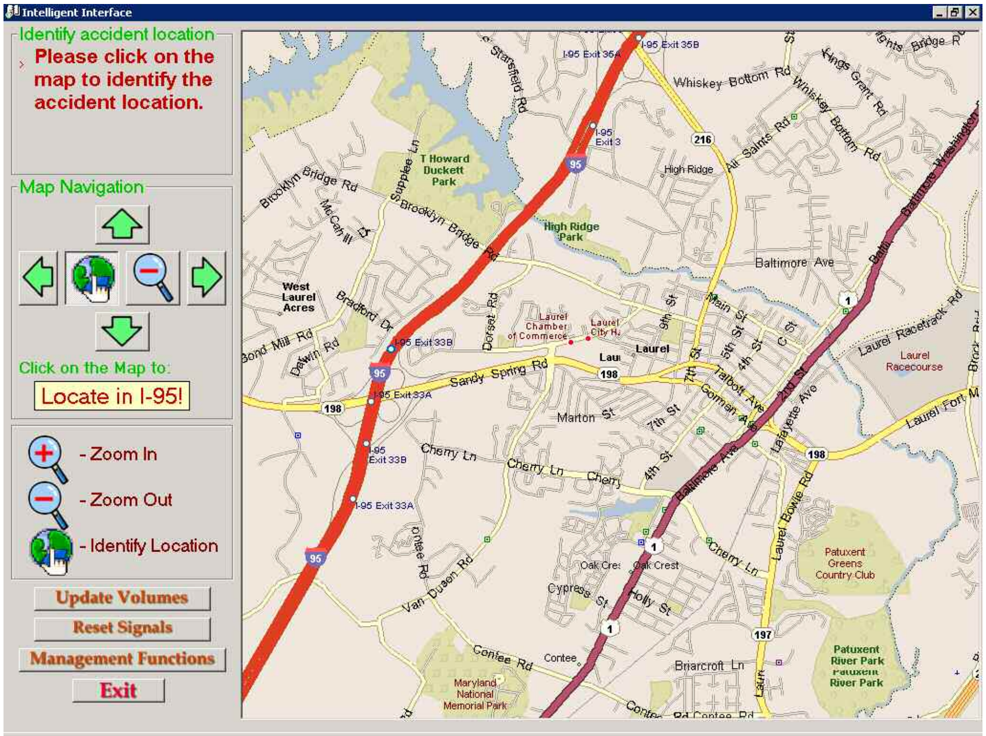
Location identification is one of the most critical functions offered by the input module. The simulator has provided the following three design alternatives for identifying the locations:

- Text-based selection
- Map-based location identification
- Simulation network-based location identification

The map-based method for location identification is based on the common design features of GIS systems, as found in the literature review. This method allows target users to experience "*ease in learning the system originally and in assimilating advanced features, confidence in the capacity to retain mastery over time, enjoyment in using the system, and eagerness to show off the system to novices*" (Shneiderman, 1983).

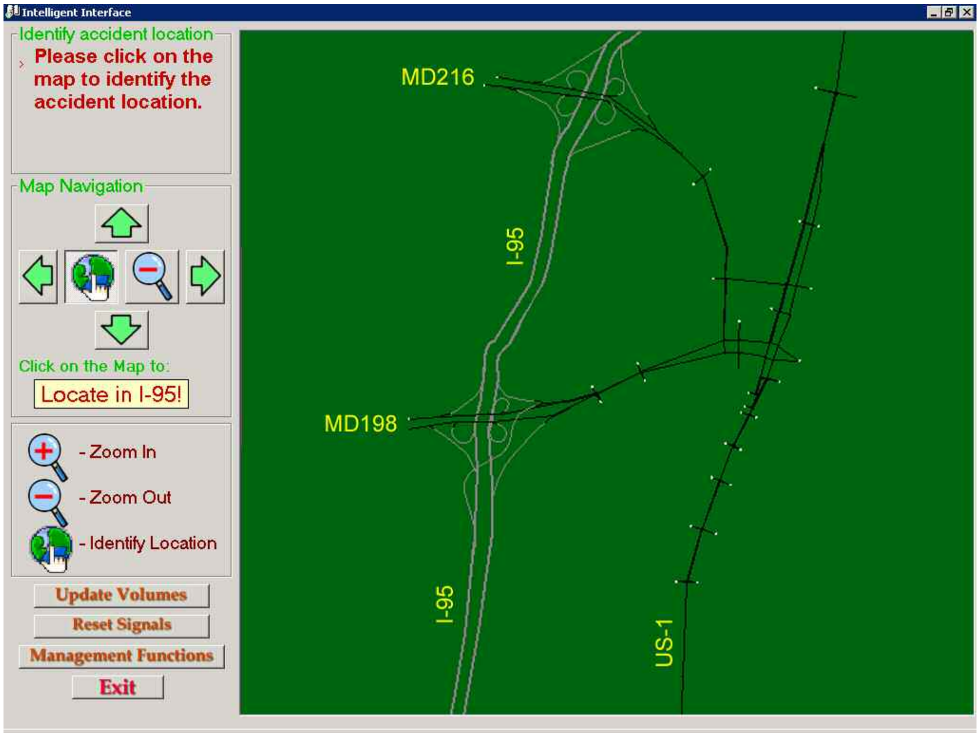
Conversely, the text-based method for location identification is not as user-friendly as the map-based interface due to the lack of functions for users to directly perform the manipulation. Based on usability tests, most users prefer the map-based system, despite the fact that it may take a relatively long time to complete the task. A comparison between the map-based interface and the simulation network-based interface is shown in Figure 6-2.

Figure 6-2 A comparison between the map-based interface and the simulation network-based interface



Please click on the map to identify the accident location.

(A map-based network)

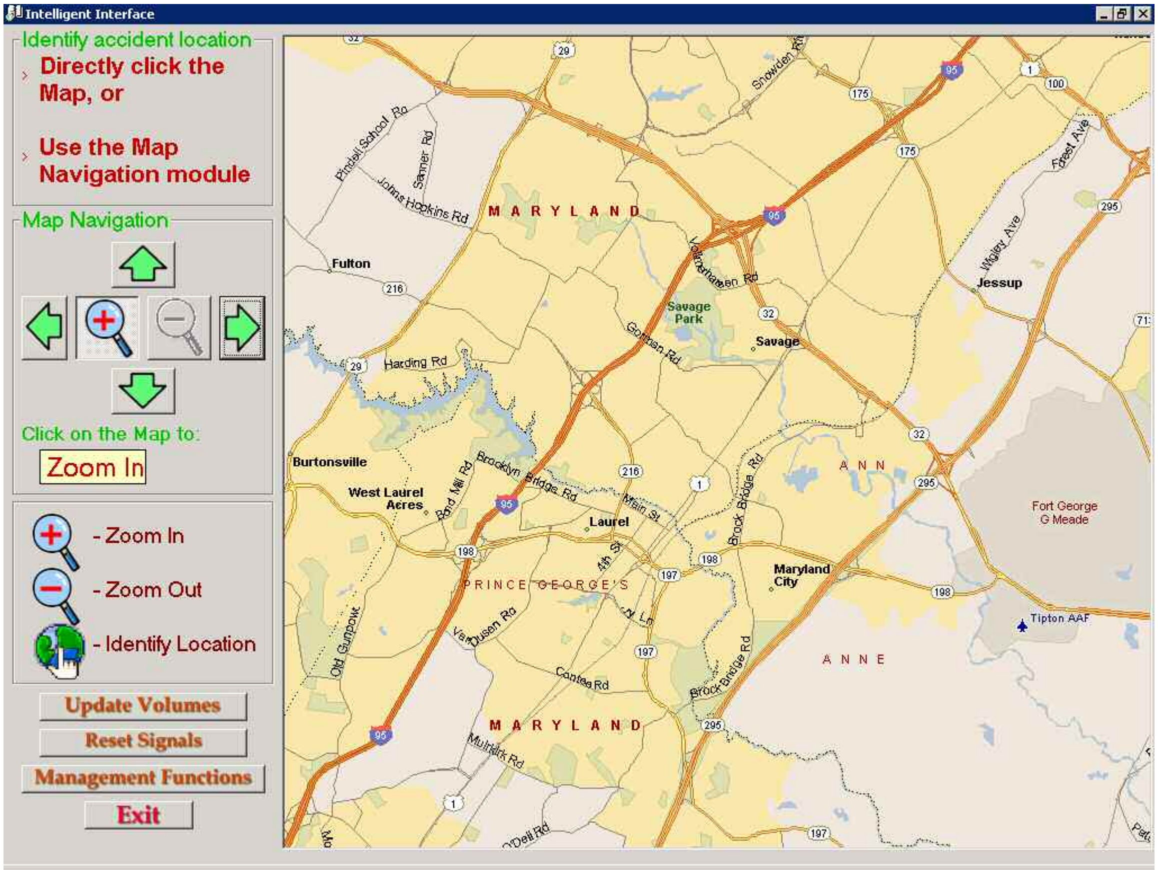


Please click on the map to identify the accident location.

(Simulation network)

The map-based interface provides two levels of functionality for location identification: an overall map for the entire area for users to identify the target freeway or arterial segments (see Figure 6-3); and a detailed map for users to zoom in and identify the exact location.

Figure 6-3 The snapshot of the input interface with an overall map view



Identify accident location

- Directly click the Map, or
- Use the Map Navigation module

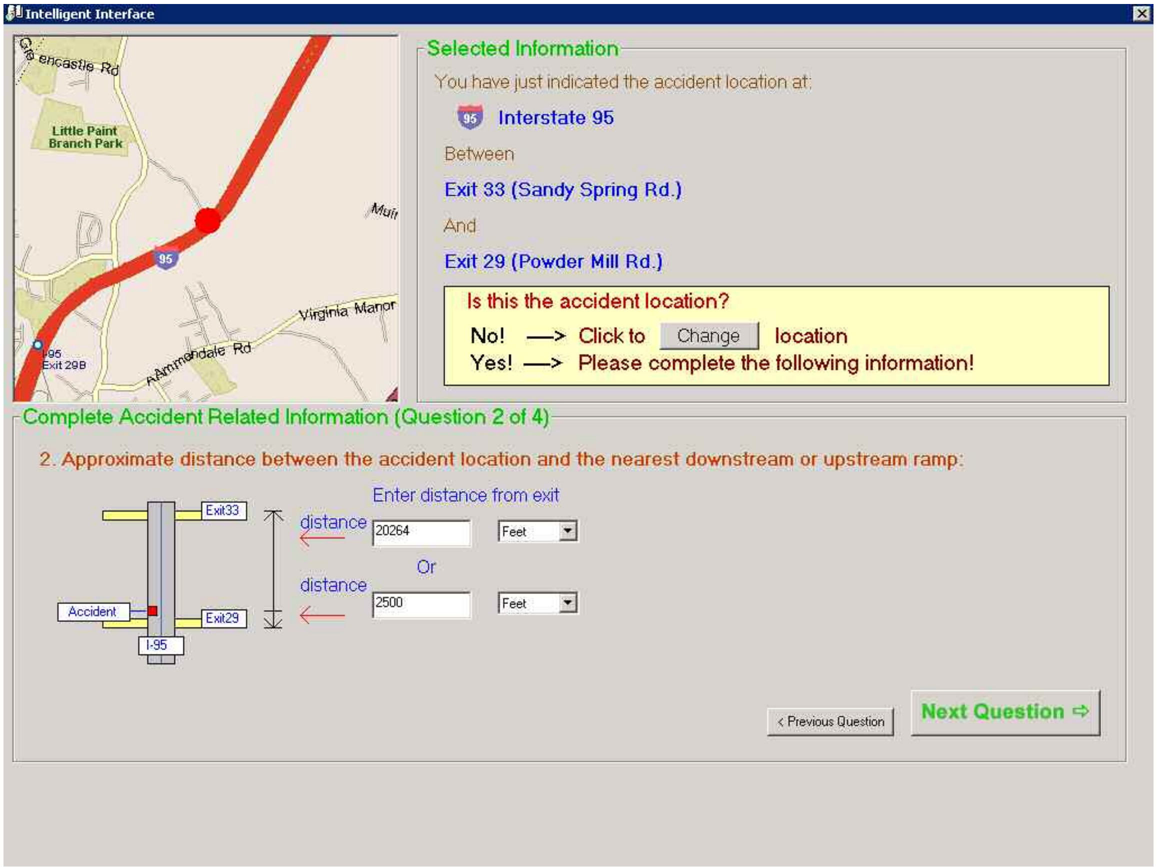
Map Navigation

Click on the Map to: Zoom In

However, a computer mouse lacks the ability to identify the location precisely; therefore, the I-95/Route-1 simulator has adopted the following two steps to improve the accuracy of this function: 1) approximate the location from the map-based interface (e.g.

between Exit 29 and Exit 33 of I-95), and 2) further indicate the precise information using a supplemental text input as shown in Figure 6-4.

Figure 6-4 A screen snapshot for users to input the distances from the incident location



Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Complete Accident Related Information (Question 2 of 4)

2. Approximate distance between the accident location and the nearest downstream or upstream ramp:

Enter distance from exit

distance 20264 Feet

Or

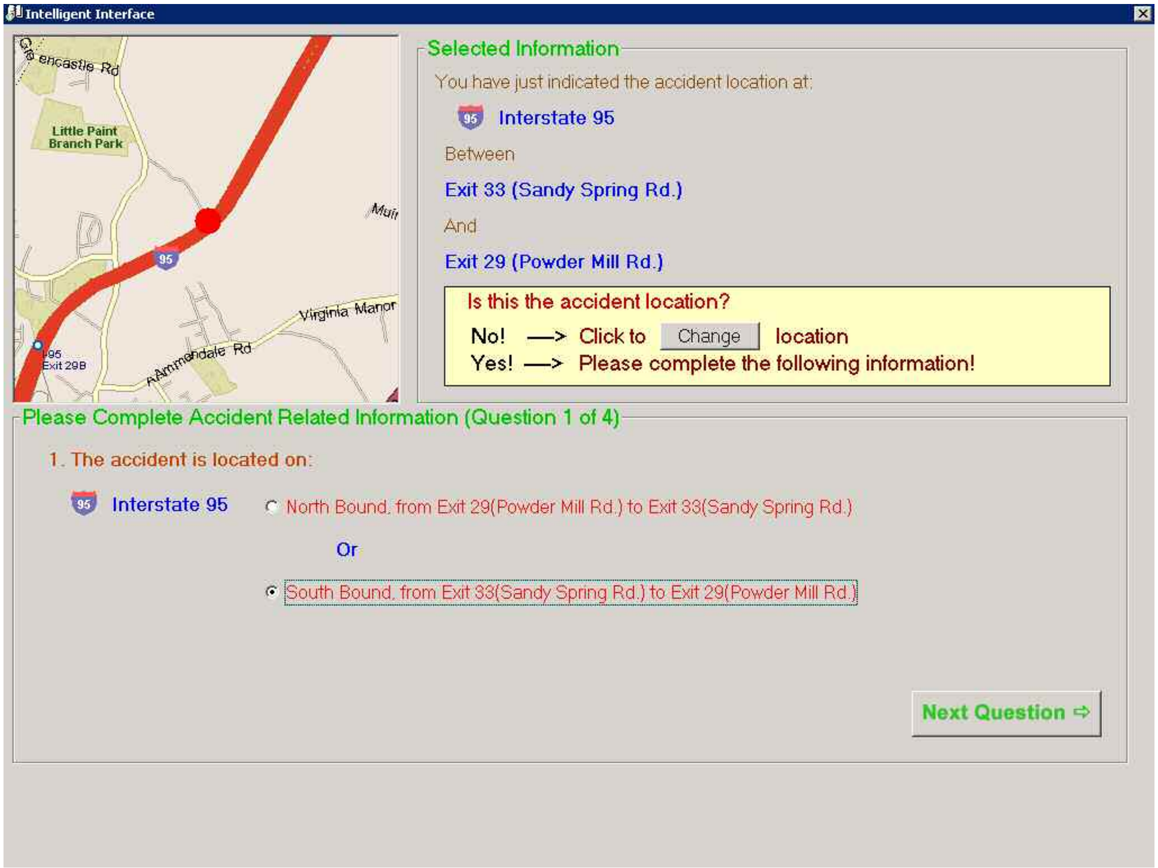
distance 2500 Feet

Required Input Information

In using the I-95/Route-1 simulator, all required information, except the approximate location identified in the map-based interfaces, is designed to be collected through subsequent interactive questions. For example, prior to executing the incident management application, users are required to answer the following four questions.

1. What is the direction of the traffic that is impacted by the incident (see Figure 6-5)?

Figure 6-5 A screen snapshot of the interface for users to input the direction of the traffic impacted by the incident



Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Please Complete Accident Related Information (Question 1 of 4)

1. The accident is located on:

Interstate 95

○ North Bound, from Exit 29(Powder Mill Rd.) to Exit 33(Sandy Spring Rd.)

Or

● South Bound, from Exit 33(Sandy Spring Rd.) to Exit 29(Powder Mill Rd.)

2. What is the distance (in feet) from the incident location to the nearest upstream or downstream ramp (see Figure 6-4)?
3. How many lanes were blocked by the reported incident (see Figure 6-6)?

Figure 6-6 A screen snapshot of the graphical interface for users to input the lane blockage information

Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Complete Accident Related Information (Question 3 of 4)

3. How many lanes have been closed?

(Click on the lanes blocked by the accident!)

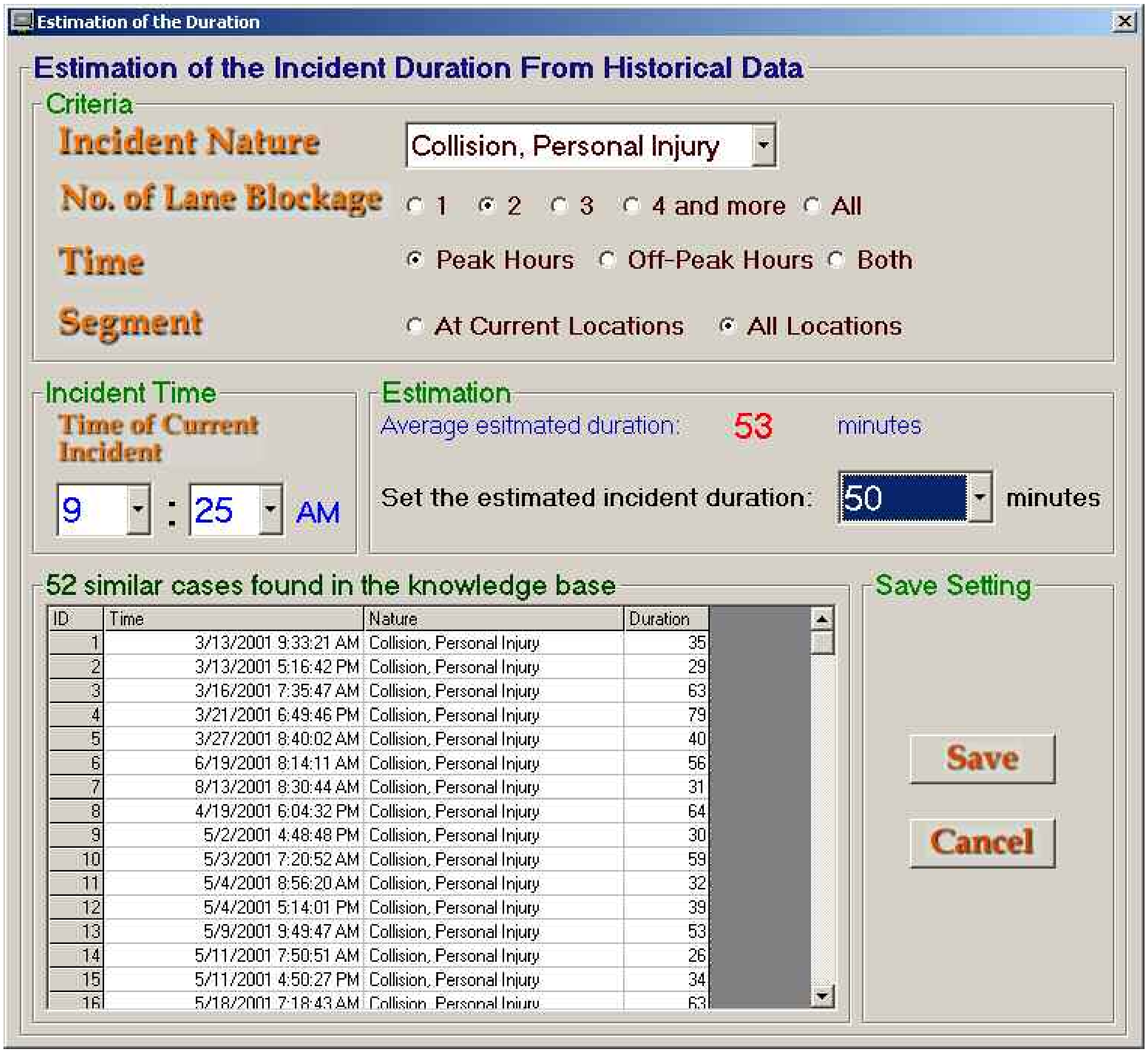
Exit33 (Sandy Spring Rd.)

Exit29 (Powder Mill Rd.)

4. What was the onset time, estimated incident duration, and the duration of simulation?

To assist users in estimating the approximate duration of a detected incident, Figure 6-7 illustrates how the simulator stores all previous incidents with similar characteristics to be used as a reference. Users can search similar cases from the archived incident database based on preset criteria such as incident nature, lane blockage, time of a day (peak hours or off-peak hours), and the location of the road segment. The system can provide both the estimated duration from an embedded statistical model and the average duration from these retrieved archived cases (see Figure 6-8).

Figure 6-7 A screen snapshot for users to input the incident starting time and the estimated duration



Estimation of the Duration

Estimation of the Incident Duration From Historical Data

Criteria

Incident Nature: Collision, Personal Injury

No. of Lane Blockage: ○ 1 ● 2 ○ 3 ○ 4 and more ○ All

Time: ● Peak Hours ○ Off-Peak Hours ○ Both

Segment: ○ At Current Locations ● All Locations

Incident Time

Time of Current Incident: 9 : 25 AM

Estimation

Average esitmated duration: 53 minutes

Set the estimated incident duration: 50 minutes

52 similar cases found in the knowledge base

ID	Time	Nature	Duration
1	3/13/2001 9:33:21 AM	Collision, Personal Injury	35
2	3/13/2001 5:16:42 PM	Collision, Personal Injury	29
3	3/16/2001 7:35:47 AM	Collision, Personal Injury	63
4	3/21/2001 6:49:46 PM	Collision, Personal Injury	79
5	3/27/2001 8:40:02 AM	Collision, Personal Injury	40
6	6/19/2001 8:14:11 AM	Collision, Personal Injury	56
7	8/13/2001 8:30:44 AM	Collision, Personal Injury	31
8	4/19/2001 6:04:32 PM	Collision, Personal Injury	64
9	5/2/2001 4:48:48 PM	Collision, Personal Injury	30
10	5/3/2001 7:20:52 AM	Collision, Personal Injury	59
11	5/4/2001 8:56:20 AM	Collision, Personal Injury	32
12	5/4/2001 5:14:01 PM	Collision, Personal Injury	39
13	5/9/2001 9:49:47 AM	Collision, Personal Injury	53
14	5/11/2001 7:50:51 AM	Collision, Personal Injury	26
15	5/11/2001 4:50:27 PM	Collision, Personal Injury	34
16	5/18/2001 7:18:43 AM	Collision, Personal Injury	63

Figure 6-8 A screen snapshot for users to input the simulation duration

Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Complete Accident Related Information (Question 4 of 4)

4. Please complete the time and the duration of the accident:

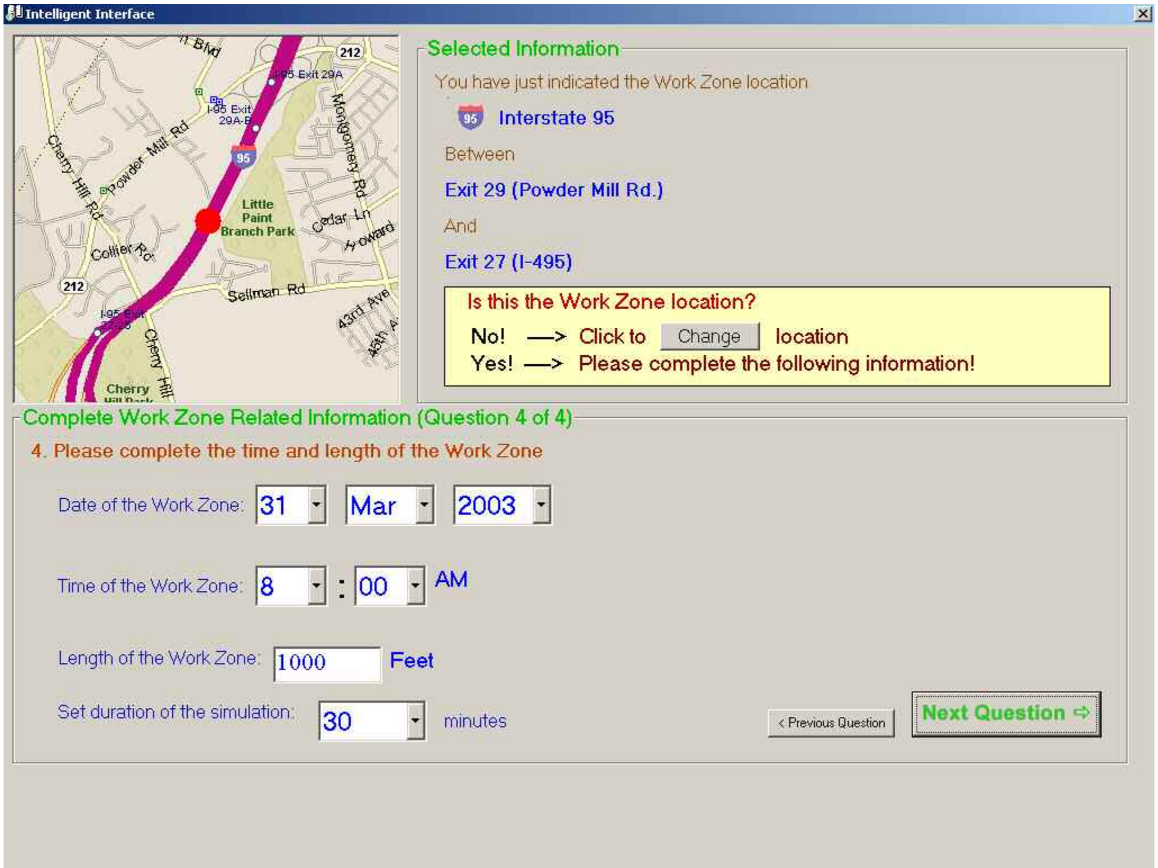
Time of the accident: 9 : 25

Duration of the incident: 50 minutes

Set the duration of simulation: 80 minutes

The set of input procedures for the work-zone operations (see Figure 6-9) is similar to those for incident management.

Figure 6-9 A snapshot of the interface for inputting information for work-zone simulation



Selected Information

You have just indicated the Work Zone location

Interstate 95

Between

Exit 29 (Powder Mill Rd.)

And

Exit 27 (I-495)

Is this the Work Zone location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Complete Work Zone Related Information (Question 4 of 4)

4. Please complete the time and length of the Work Zone

Date of the Work Zone: 31 Mar 2003

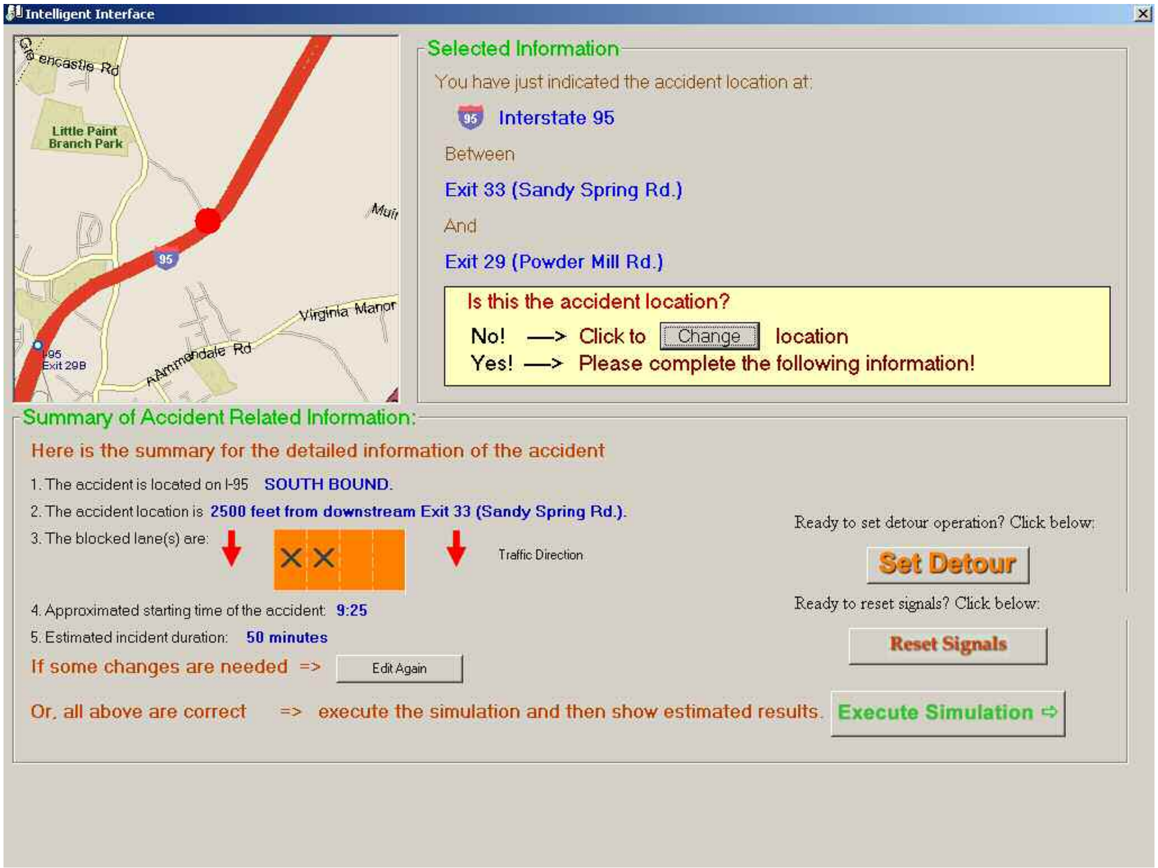
Time of the Work Zone: 8 : 00 AM

Length of the Work Zone: 1000 Feet

Set duration of the simulation: 30 minutes

Note that, as shown from Figure 6-4 to Figure 6-10, a preview window of all location information input by the user will be continuously displayed on the screen. The purpose of this window is to allow users to review all input data and make necessary corrections or changes in a timely manner using the map-based interface.

Figure 6-10 A summary screen for users to review all input information for simulating incident impacts



Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Summary of Accident Related Information:

Here is the summary for the detailed information of the accident

1. The accident is located on I-95 SOUTH BOUND.
2. The accident location is 2500 feet from downstream Exit 33 (Sandy Spring Rd.).
3. The blocked lane(s) are: Traffic Direction
4. Approximated starting time of the accident: 9:25
5. Estimated incident duration: 50 minutes

If some changes are needed => Edit Again

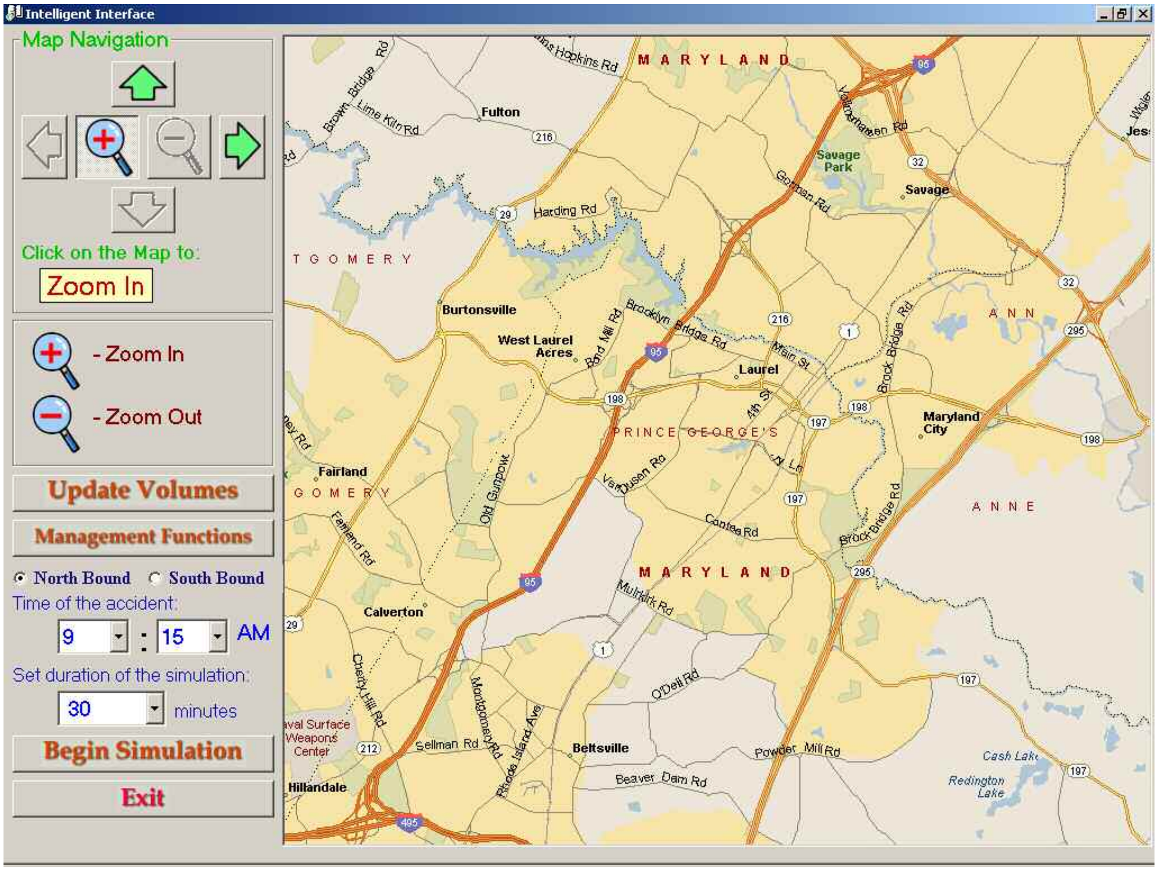
Or, all above are correct => execute the simulation and then show estimated results.

Ready to set detour operation? Click below:

Ready to reset signals? Click below:

Subsequent to receiving all required data, the simulator will display a summary of all input information for users to review (see Figure 6-10). The simulator only requires the target traffic direction, start time, and duration of the simulation (See Figure 6-11) for recurrent congestion monitoring.

Figure 6-11 The input interface for recurrent congestion monitoring



● North Bound ○ South Bound

Time of the accident: 9 : 15 AM

Set duration of the simulation: 30 minutes

Volume Update

The volume update function is designed to assist users in updating the entry volume of the network and the turning movement percentages for each ramp and/or intersection (see Figure 6-12). The input volume data is in the format of vehicles per hour.

Figure 6-12 The interface for users to update the volume

Input Volumes for Exit 38

Ramp Volumes

A 1182
B 500
C 5029
D 841
E 349
F 125
G 633
H 980

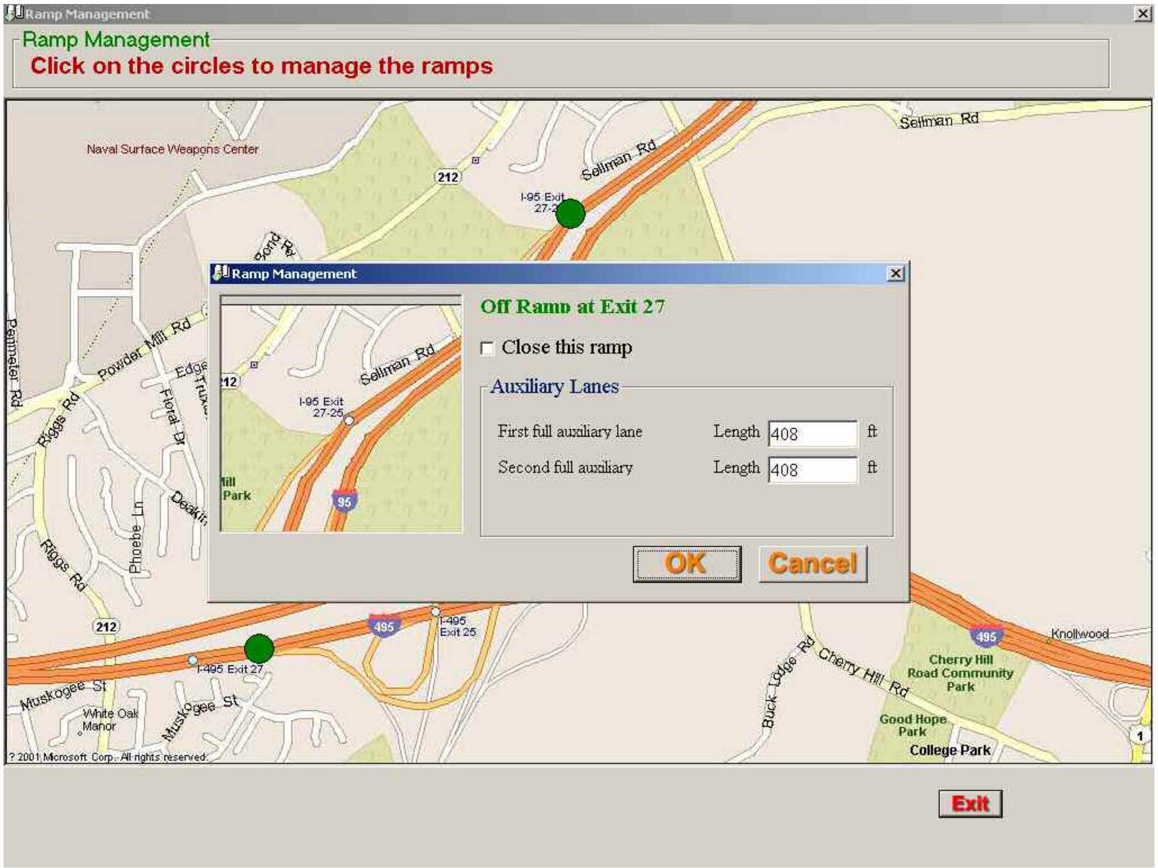
Entry Volumes

1 3100
2 250

Ramp Access Control

The purpose of the ramp access control function is to assist users in assessing the effectiveness of traffic management strategies, such as detour operations during severe accidents, to mitigate the resulting congestion. This function also allows users to evaluate the potential impacts of changing the length of auxiliary lanes for traffic merging conditions during the period of incident control and management (see Figure 6-13).

Figure 6-13 The interface for users to close the ramp and/or change the length of the auxiliary lanes


Ramp Management

Ramp Management

Click on the circles to manage the ramps

Ramp Management

Off Ramp at Exit 27

☐ Close this ramp

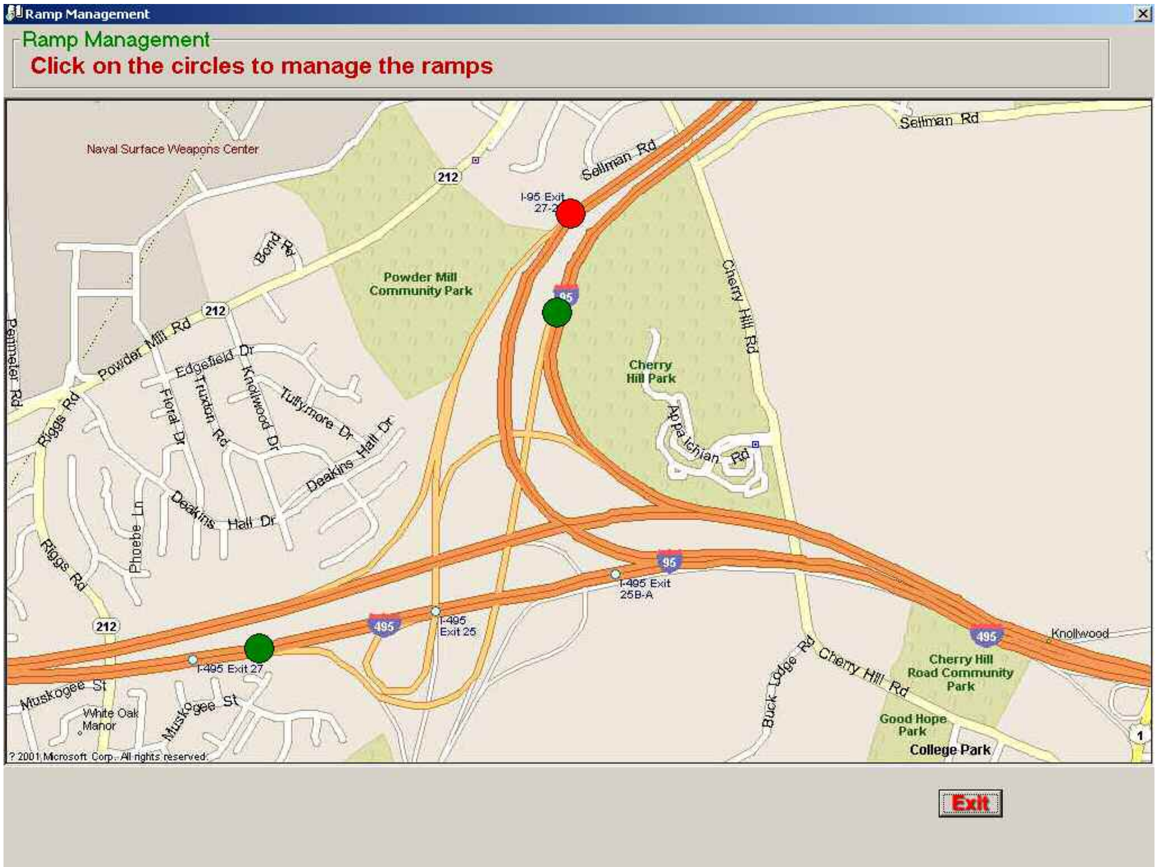
Auxiliary Lanes

First full auxiliary lane Length 408 ft

Second full auxiliary Length 408 ft

Figure 6-14 illustrates the interchange between I-95 and I-495 with one ramp closed during incident management.

Figure 6-14 The main screen of the ramp management with one ramp closed



Click on the circles to manage the ramps

Detour Operations

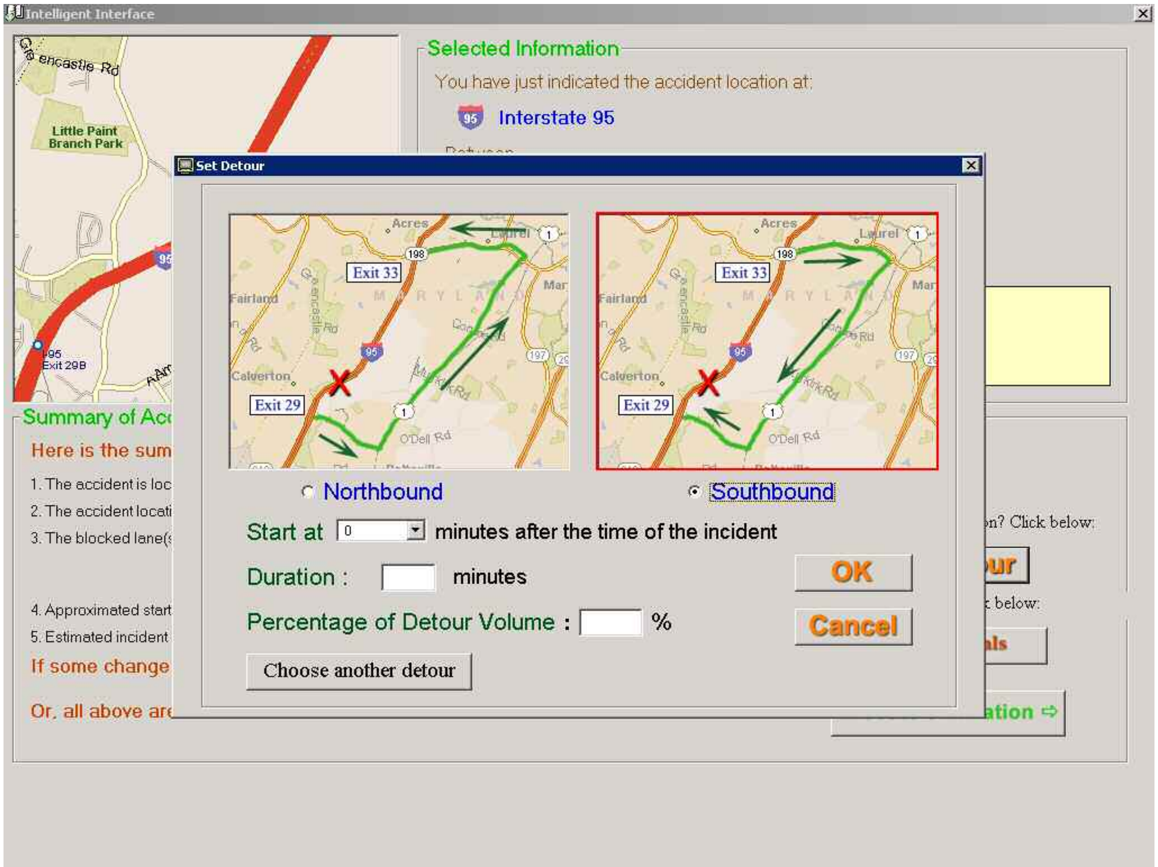
In the I-95/Route-1 corridor between Capital Beltway (I-495) and the Baltimore Beltway (I-695), a total of 9 preset detour routes (see Figure 6-15) have been established by MDSHA for use during severe incidents. Each detour plan intends to detour traffic between two adjacent interchanges. Users can take the default detour route or input their selected routes for simulation and evaluate the potential impacts on the freeway and arterial.

Figure 6-15 The set of detour routes for I-95/Route-1 by MDSHA

Please click on the image to choose the detour plan, or click Exit button to return

The required input for detour operations is the start time, duration, and the expected percentage of detoured volumes (see Figure 6-16).

Figure 6-16 The input interface for the detour operation



Selected Information

You have just indicated the accident location at:

Interstate 95

Summary of Acc

Here is the sum

1. The accident is loc
2. The accident locati
3. The blocked lane(
4. Approximated start
5. Estimated incident

If some change

Or, all above are

○ Northbound ● Southbound

Start at 0 minutes after the time of the incident

Duration : minutes

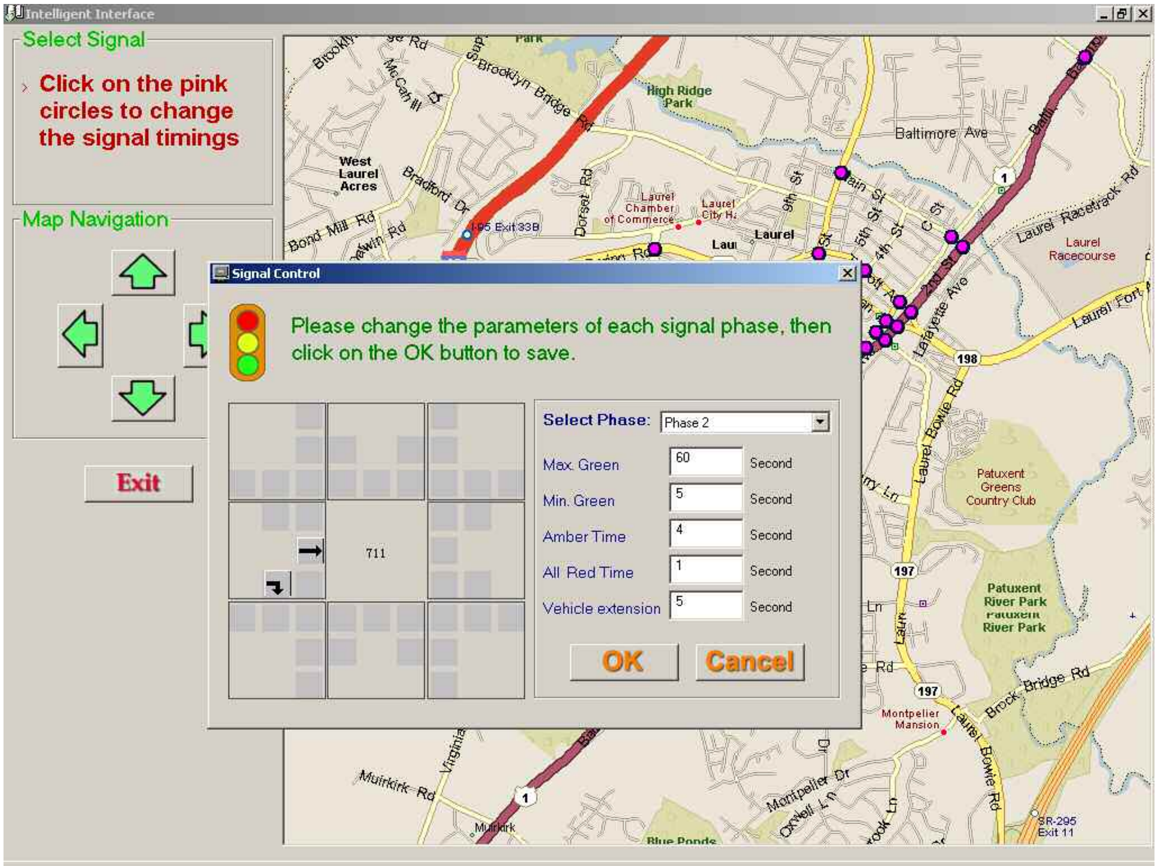
Percentage of Detour Volume : %

Choose another detour

Signal Timings

The signal timing function is designed to accommodate detour volumes on arterials with sufficient green time during incident management. Users can change all key signal control parameters prior to execution of simulation, including the maximum green time, minimum green time, yellow time, all red time, and vehicle extension time for each phase (Figure 6-17).

Figure 6-17 The interface for the change of the signal timing



Click on the pink circles to change the signal timings

Please change the parameters of each signal phase, then click on the OK button to save.

Select Phase: Phase 2

Max. Green 60 Second
Min. Green 5 Second
Amber Time 4 Second
All Red Time 1 Second
Vehicle extension 5 Second

6.3. Principal output features for applications

Analysis of the Simulation Results

To manage traffic during either recurrent or non-recurrent congestion, responsible traffic engineers and personnel like to have the following information available.

- Delay: the difference between free-flow and actual travel times for vehicles to travels over the target highway segment.
- Average Speed: the space-mean speed of all vehicles traveling over the target highway segment during the period of interest.
- Travel Time: the time duration for vehicles to travel over the target highway segment
- Queue information: the number of vehicles moving in platoons with average speeds below the default value of 15 mpg. Users can change the default value for defining traffic queue information based on their needs.

Organization of the Output Module

As shown in Figure 6-18, the simulator is designed to allow users to quickly find the right category of information by highlighting the target application and selecting the type of chart by segment (see Figure 6-18) or time interval (see Figure 6-19). Users can also make the following choices after review of the simulation output:

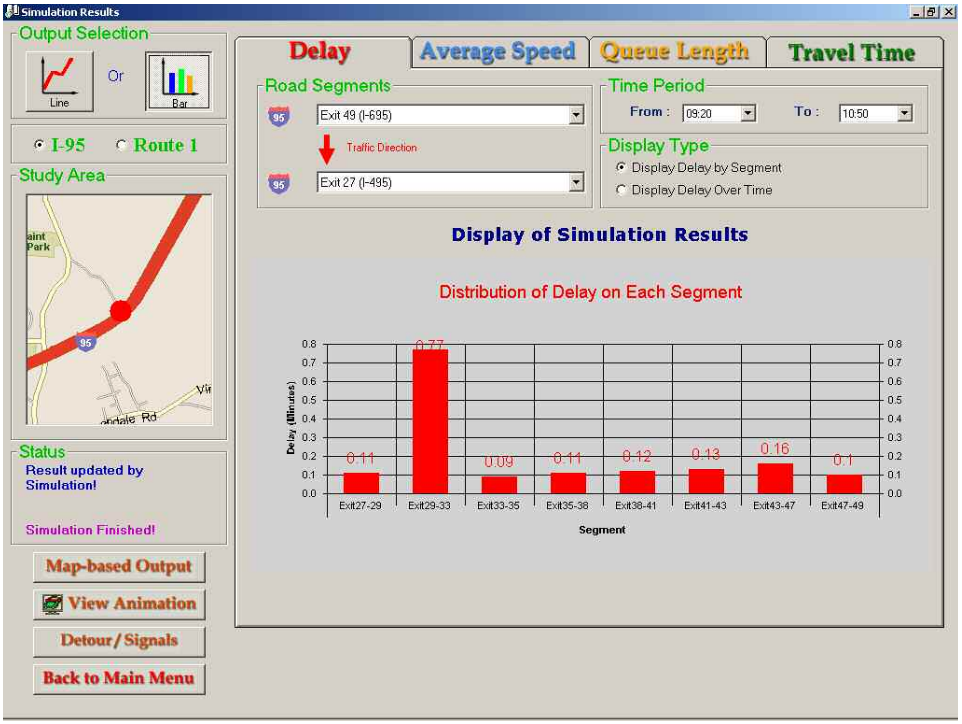
- Presentation of the output by either line graphics (see Figure 6-20) or bar charts
- Target segments in the network

- Target time period of interests

Chart-based Output:

This output can easily display the distribution of traffic characteristics over a time interval of interest or by highway segment. It also allows users to better understand the evolution of traffic over time at different segments of the network.

Figure 6-18 Delay tab in the four categories of the chart-based output



Road Segments: Exit 49 (I-695) → Exit 27 (I-495)

Time Period: From : 09:20 To : 10:50

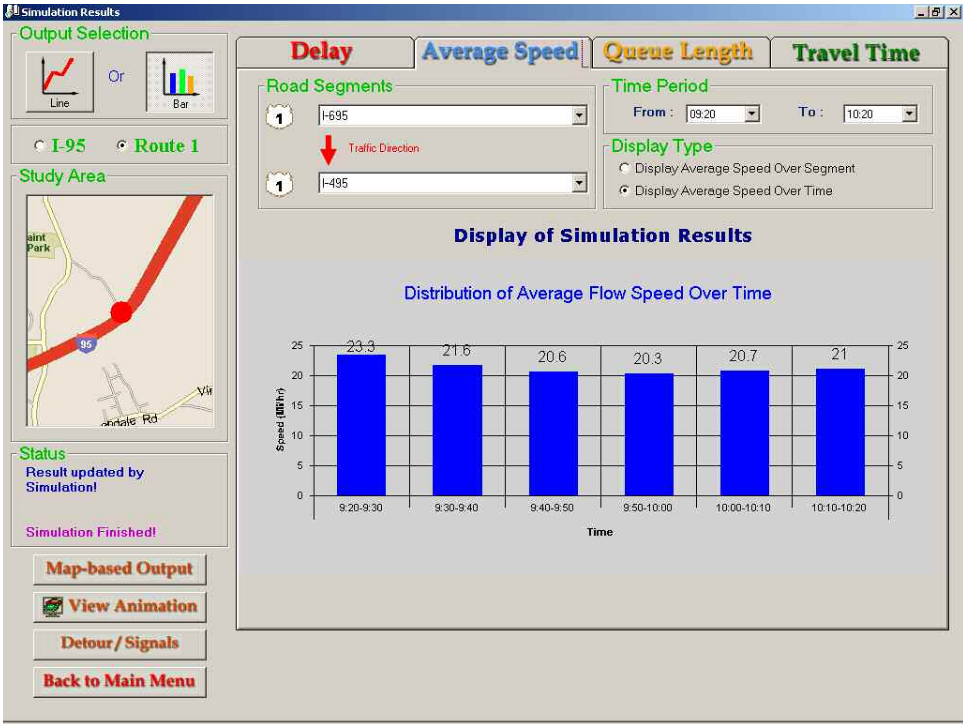
Display Type:
● Display Delay by Segment
○ Display Delay Over Time

● I-95 ○ Route 1

Status: Result updated by Simulation!

Simulation Finished!

Figure 6-19 A bar chart-based output for the average speed on Route-1 over time


Simulation Results

Output Selection

○ I-95 ● Route 1

Road Segments: I-695

Traffic Direction

I-495

Time Period From : 09:20 To : 10:20

Display Type

○ Display Average Speed Over Segment

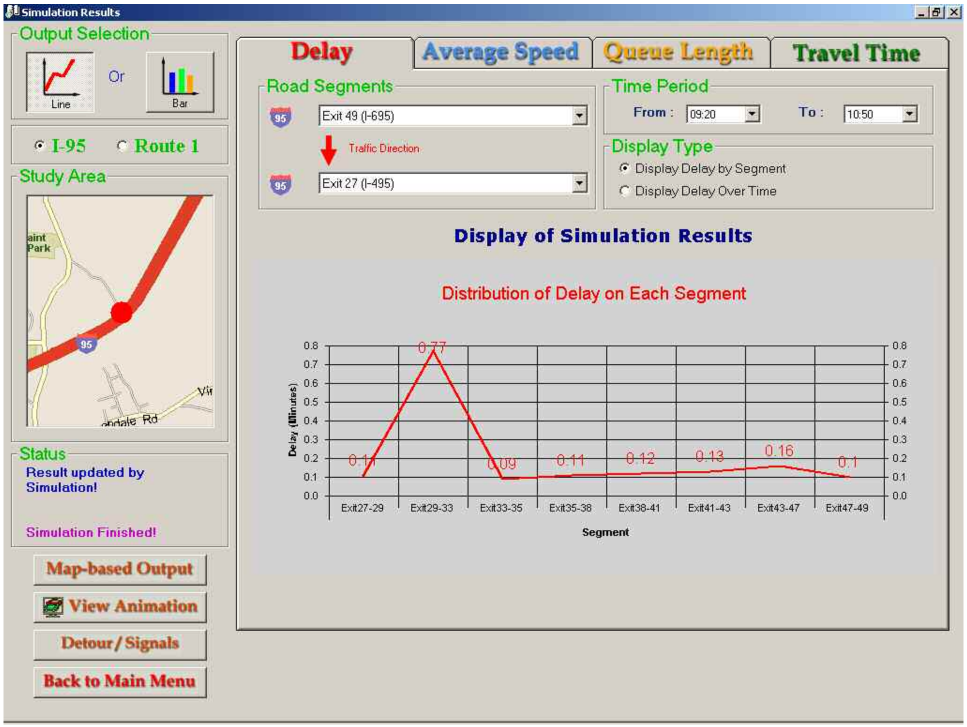
● Display Average Speed Over Time

Status: Result updated by Simulation!

Simulation Finished!

Display of Simulation Results

Figure 6-20 A line graphic of the distribution of delay by segment


Simulation Results

Output Selection

● I-95 ○ Route 1

Road Segments: Exit 49 (I-695)

Traffic Direction

Exit 27 (I-495)

Time Period From : 09:20 To : 10:50

Display Type

● Display Delay by Segment

○ Display Delay Over Time

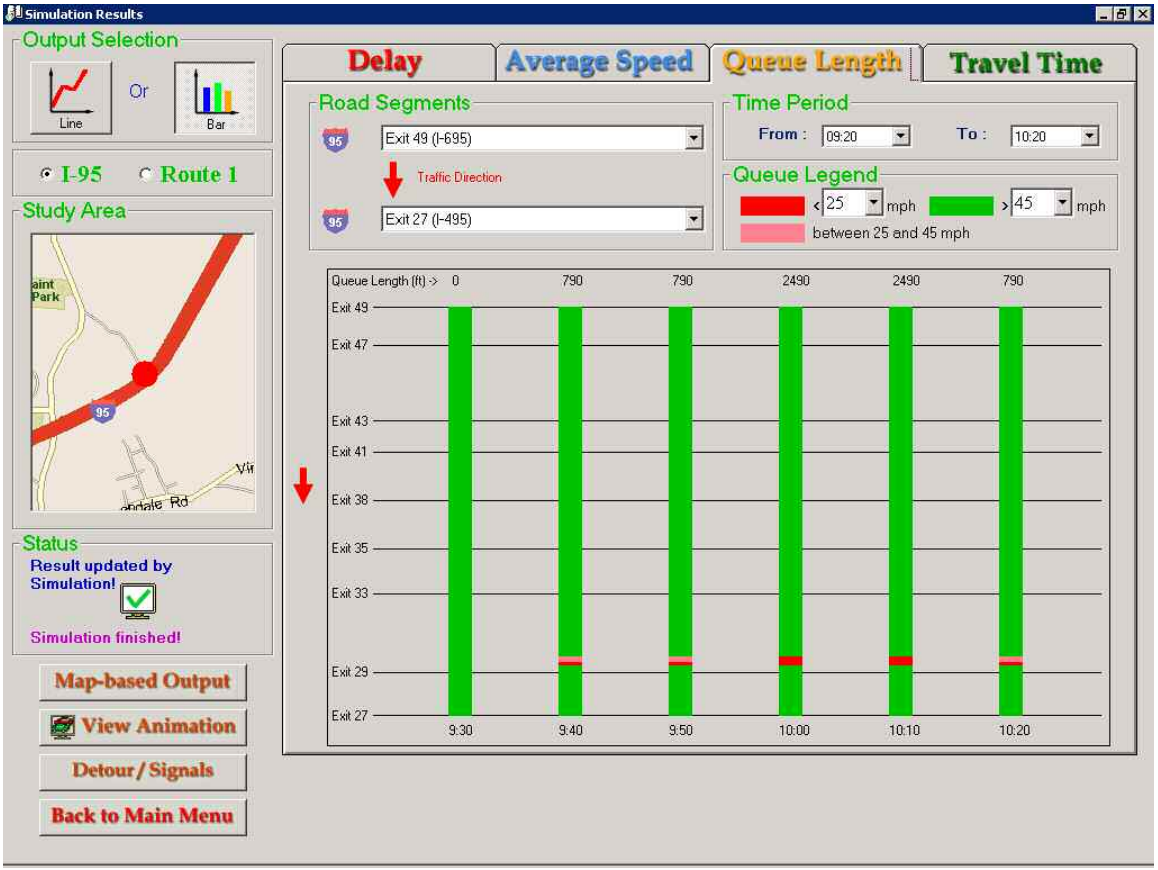
Status: Result updated by Simulation!

Simulation Finished!

Display of Simulation Results

Figure 6-21 presents queue information displayed by the simulator. In this example, the number on the top of each bar represents the total length of the queue (in feet) over the displayed segment, and the horizontal axis represents the queue evolution over time. This type of information can help users understand the evolution of traffic queues and congestion levels during specific time periods.

Figure 6-21 The output screen of the queue length



Road Segments: Exit 49 (I-695) to Exit 27 (I-495)

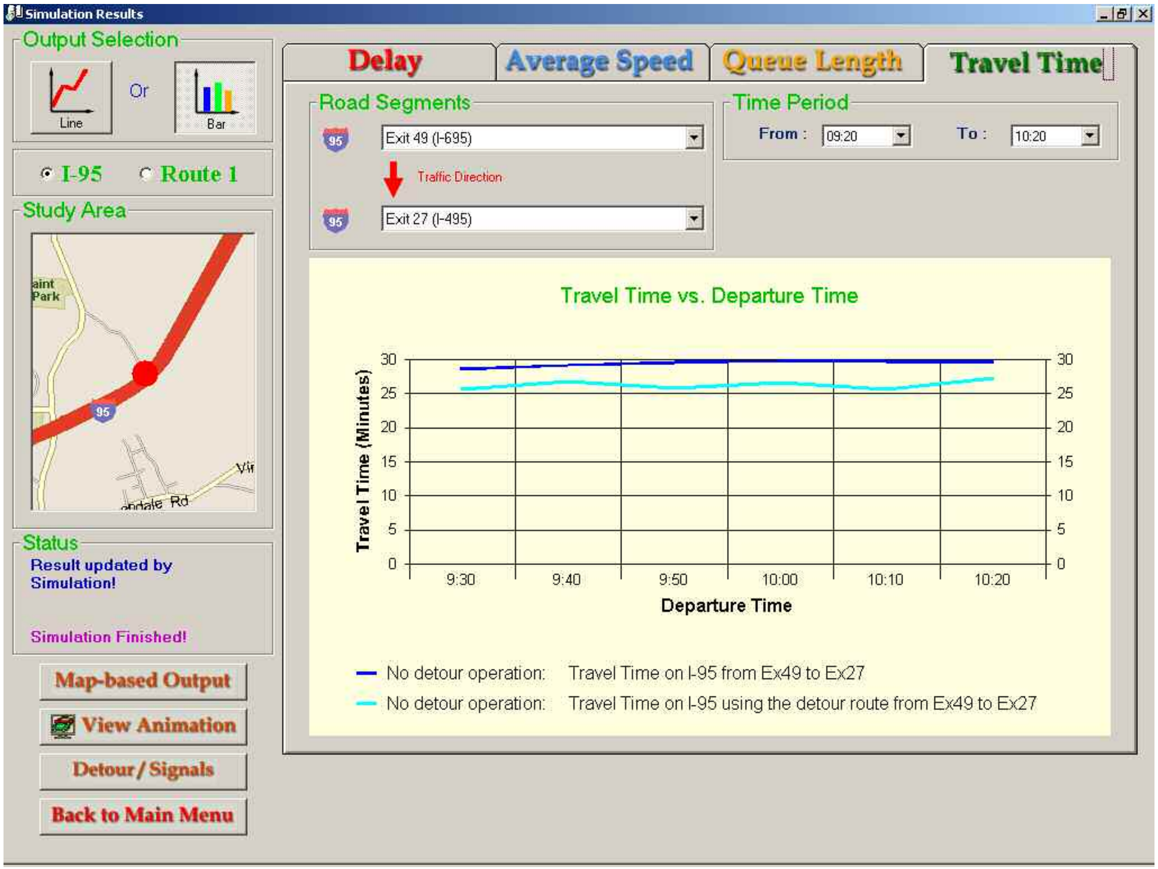
Time Period From : 09:20 To : 10:20

Result updated by Simulation!

Simulation finished!

The travel times from different origins to various destinations over time are illustrated in the output module using a line chart (see Figure 6-22). The time needed to travel on specified road segments, at different departure times, serves as the foundation for traveler information systems. If no detour operation is implemented, the simulator will display travel time via the I-95 only, and the travel time by using I-95 and the default detour route to circumvent the incident segment. The potential benefit of taking the detour route could encourage drivers to make proper choices when selecting routes.

Figure 6-22 The output of the travel time vs. departure time with no detour operation



Simulation Results

Output Selection: Line Or Bar

● I-95 ○ Route 1

Road Segments: Exit 49 (I-695) → Exit 27 (I-495)

Traffic Direction

Time Period — From : 09:20 To : 10:20

Status: Result updated by Simulation!

Simulation Finished!

Travel Time vs. Departure Time

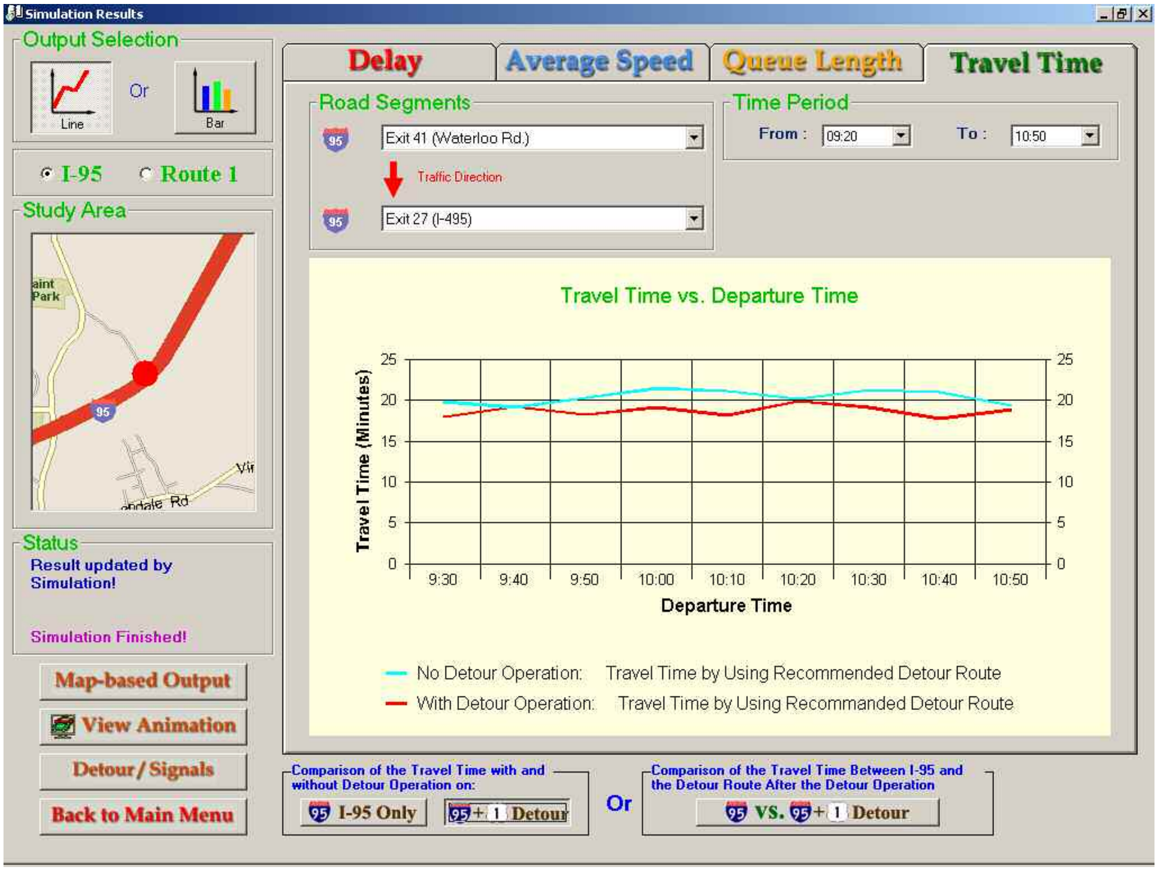
No detour operation: Travel Time on I-95 from Ex49 to Ex27

No detour operation: Travel Time on I-95 using the detour route from Ex49 to Ex27

Control center operators can also use the I-95/Route-1 simulator to evaluate the benefits of detouring traffic via preset detour routes during severe accidents (see Figure 6-23). Once the execution is complete, the simulator will provide the following four types of information:

1. Delay
2. Average speed
3. Queue length
4. Travel time

Figure 6-23 Comparison of the travel time vs. departure time via the detour route before and after the detour operation



● I-95 ○ Route 1

Exit 41 (Waterloo Rd.)

Exit 27 (I-495)

From : 09:20 To : 10:50

Result updated by Simulation!

Simulation Finished!

No Detour Operation: Travel Time by Using Recommended Detour Route

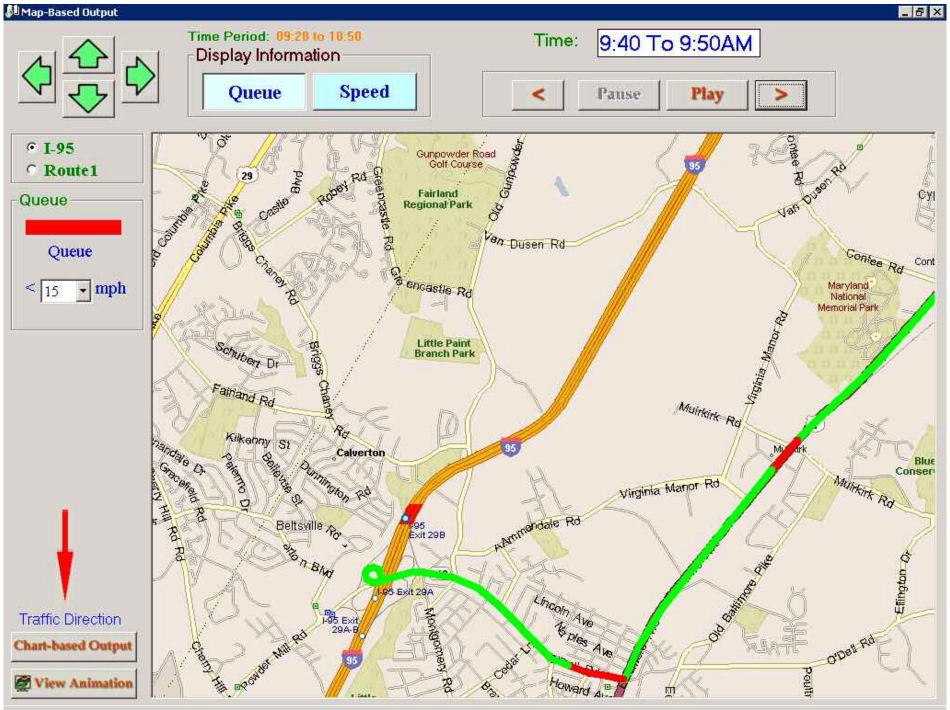
With Detour Operation: Travel Time by Using Recommanded Detour Route

Map-based Output:

When looking at the target queue, color coded map based output can better assist users in understanding the spatial distribution of traffic conditions, including the distribution of the traffic queue (Figure 6-24) and average speeds (Figure 6-25).

Users can also change the definition of the queue. For example, traffic with speed below 15mph is defined as queue (e.g. in red color) in Figure 6-24.

Figure 6-24 The map-based output of traffic queue on both I-95 and detour route



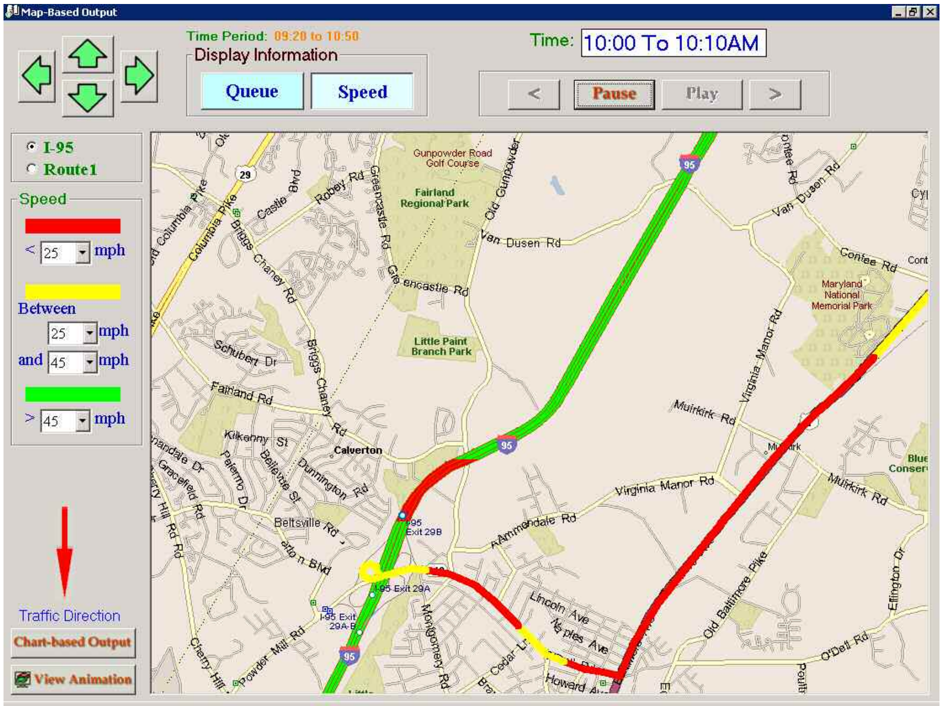
Time Period: 09:20 to 10:50

Time: 9:40 To 9:50AM

● I-95
○ Route1

Queue: < 15 mph

Figure 6-25 The map-based output of the average speed on both I-95 and the detour route


Time Period: 09:20 to 10:50

Time: 10:00 To 10:10AM

● I-95
○ Route1

Speed

🟥 < 25 mph

🟨 Between 25 mph and 45 mph

🟩 > 45 mph

Chapter 7. Example Application and Future Enhancement

7.1. Example Application

The following incident scenario is used to present the operating process of the developed I-95/Route-1 simulator.

Incident Scenario:

At 9:25AM, an incident occurred on southbound I-95 between exit 29 and exit 33. Two right lanes have been blocked. The location of the incident is about 2500 feet north of exit 29.

Operations using the I-95/Route-1 Simulator:

Upon receiving the incident report, the control center operator will follow the eight steps listed below using the I-95/Route-1 simulator:

Step 1: Activate the I-95/Simulator and execute the incident management function from the main menu (see Figure 7-1).

Figure 7-1 Main menu of the I-95/Route-1 simulator

Step 2: Zoom in the interface map to the segment of I-95/Route-1 corridor between exit 29 and exit 33, and click on the map to identify the incident area (see Figure 7-2 and Figure 7-3).

Figure 7-2 An overall map of I-95/Route-1 displayed by the simulator

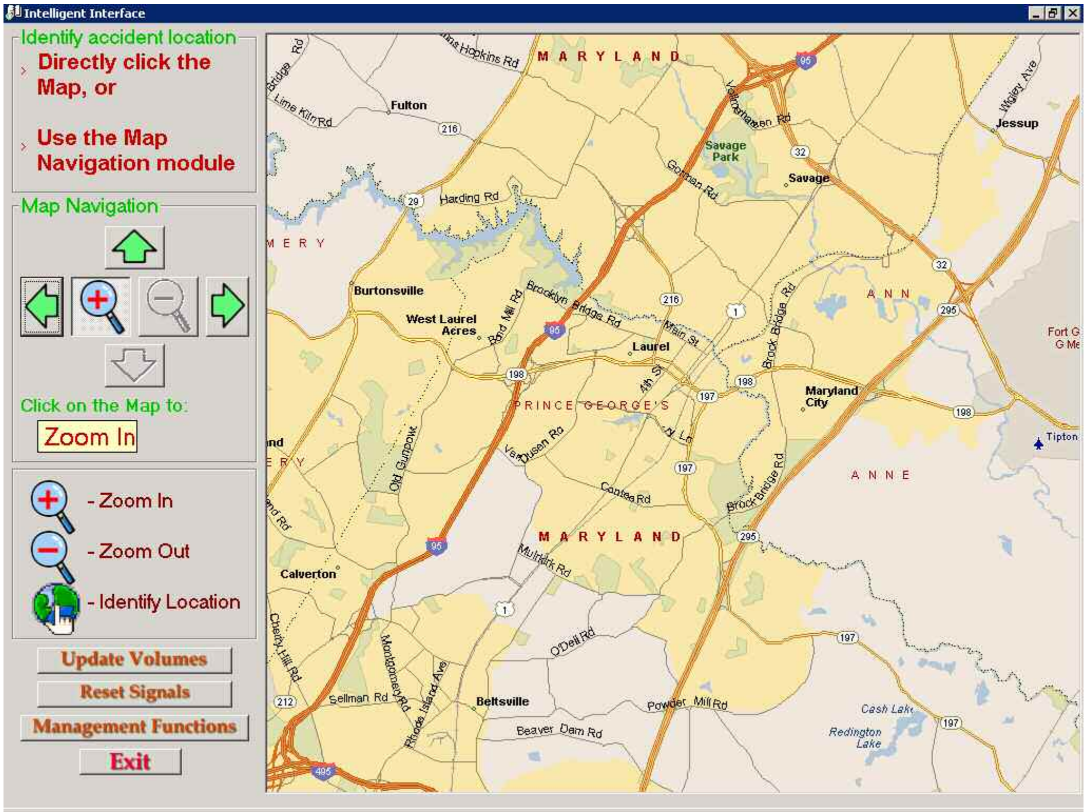
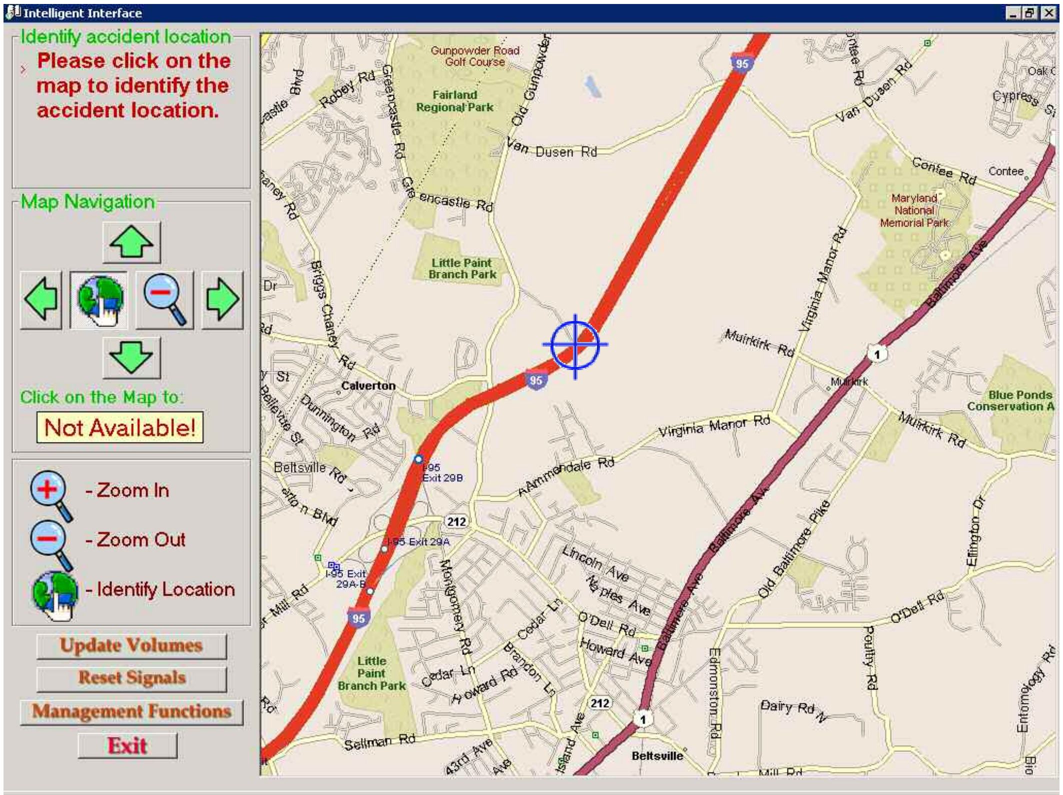


Figure 7-3 A detailed map view for segment between exit 29 and exit 33 on I-95



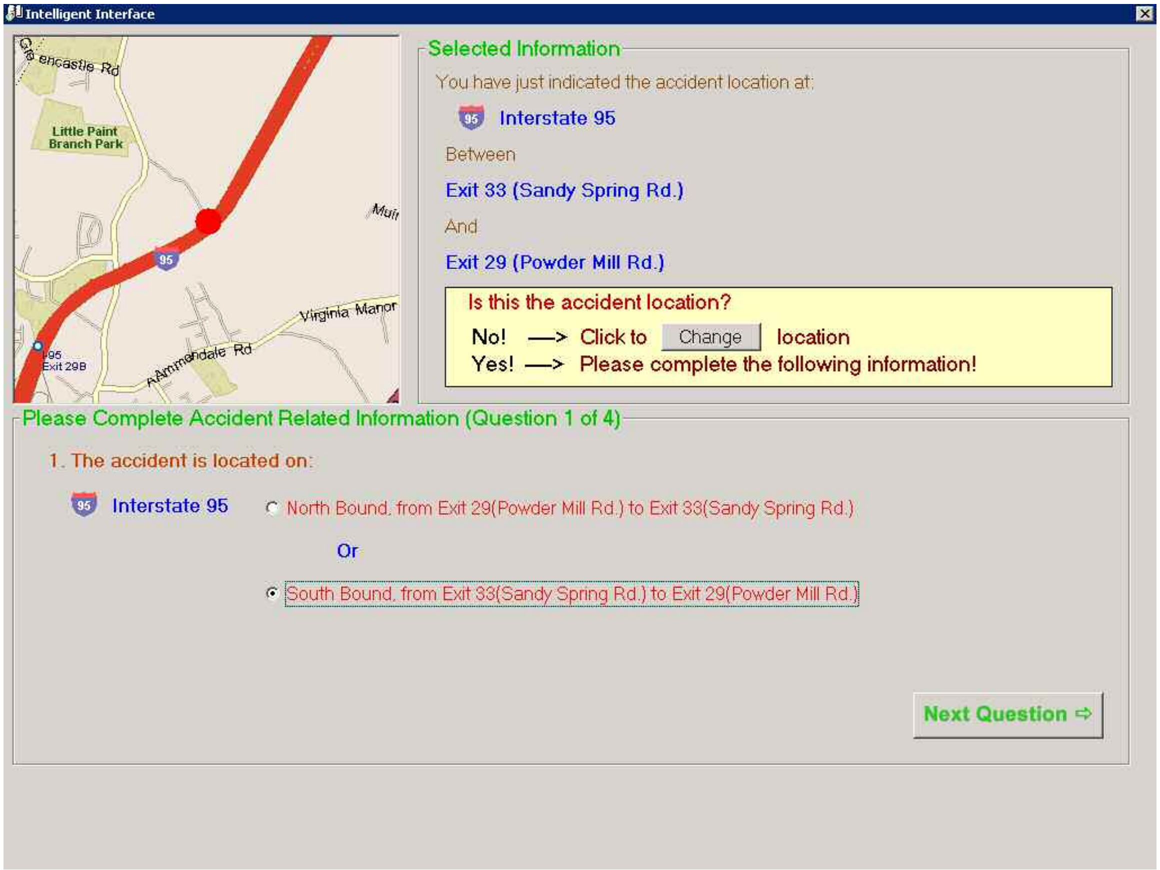
Identify accident location

Please click on the map to identify the accident location.

Step 3: Input information related to the detected incident by answering the following preset questions:

I. What is the direction of traffic?

Figure 7-4 The interface for users to input blocked traffic direction



Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Please Complete Accident Related Information (Question 1 of 4)

1. The accident is located on:

Interstate 95

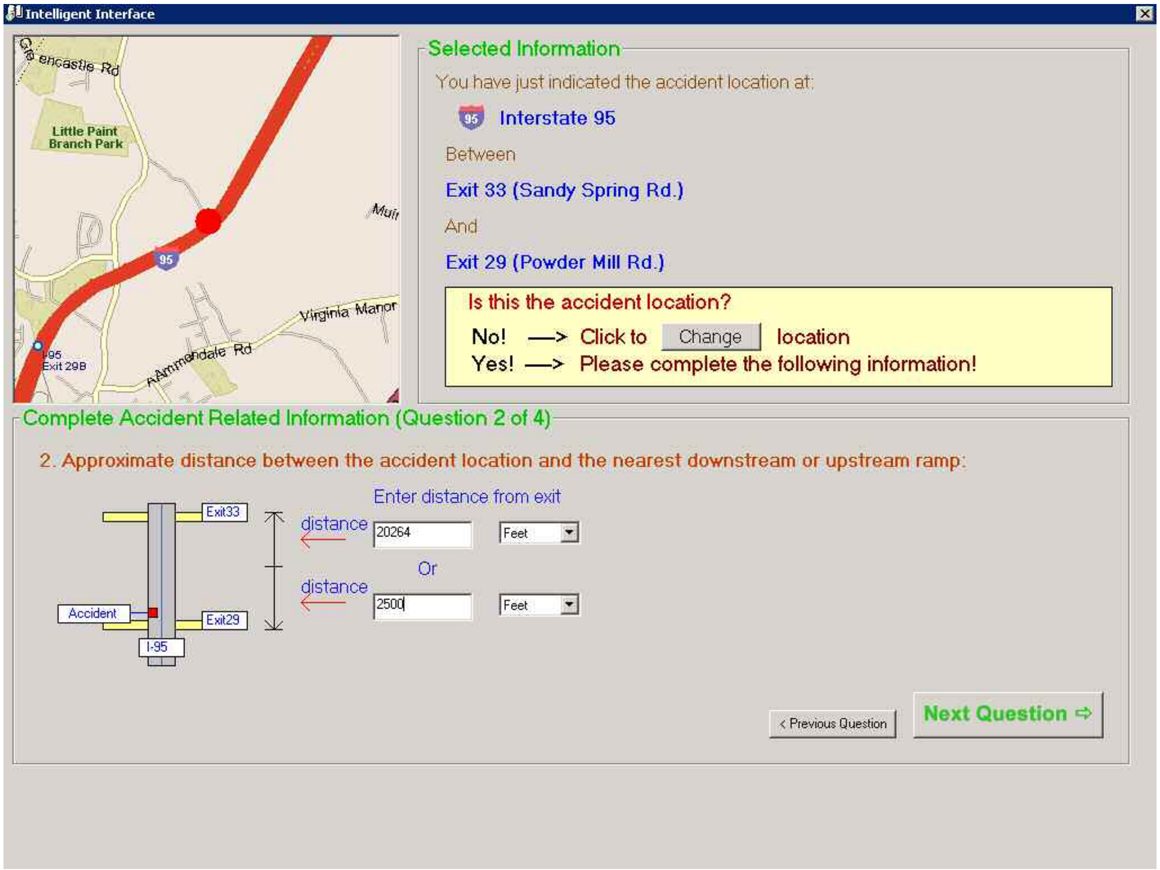
○ North Bound, from Exit 29(Powder Mill Rd.) to Exit 33(Sandy Spring Rd.)

Or

● South Bound, from Exit 33(Sandy Spring Rd.) to Exit 29(Powder Mill Rd.)

II. Where is the precise accident location?

Figure 7-5 The interface for users to input precise location information



Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Complete Accident Related Information (Question 2 of 4)

2. Approximate distance between the accident location and the nearest downstream or upstream ramp:

Enter distance from exit

distance 20264 Feet

Or

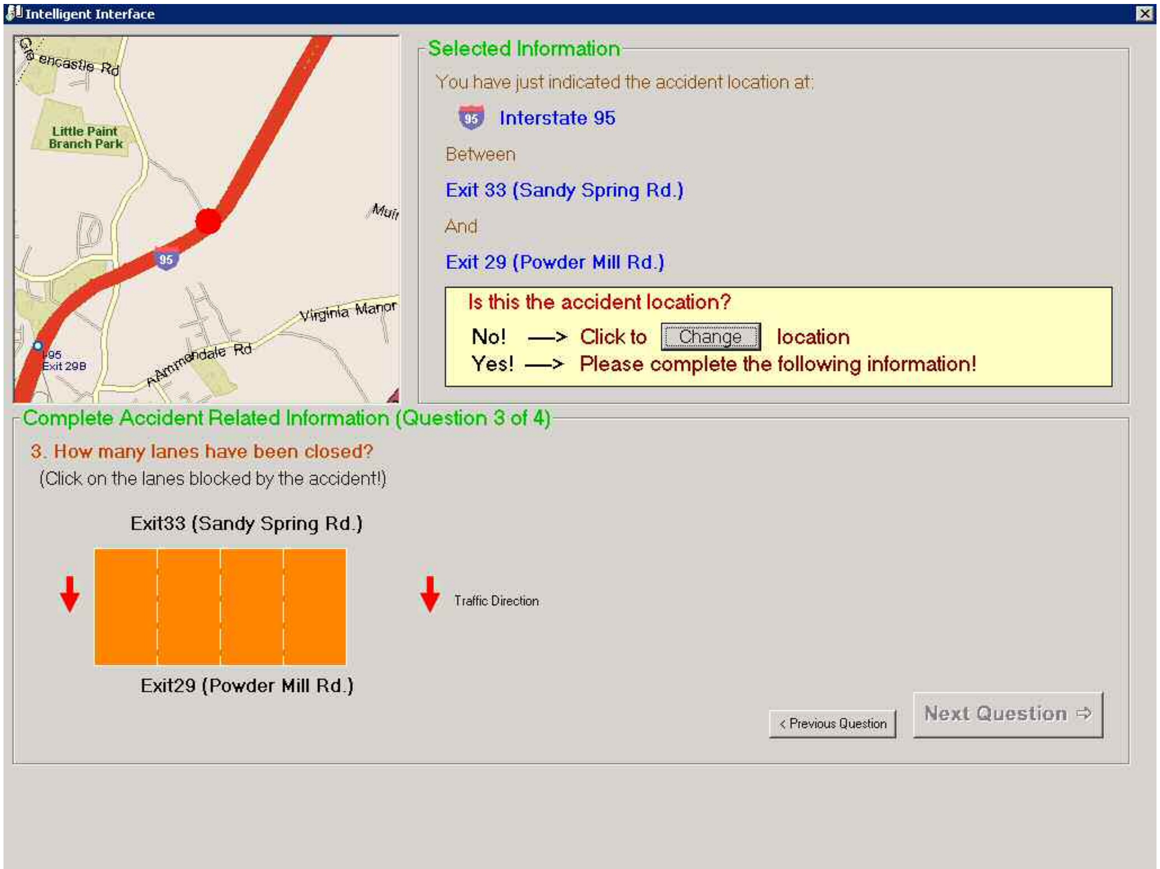
distance 2500 Feet

< Previous Question

Next Question ⇨

III. Are there any lanes being blocked?

Figure 7-6 The interface for users to mark blocked lanes



Selected Information

You have just indicated the accident location at:

95 Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Complete Accident Related Information (Question 3 of 4)

3. How many lanes have been closed?

(Click on the lanes blocked by the accident!)

Exit33 (Sandy Spring Rd.)

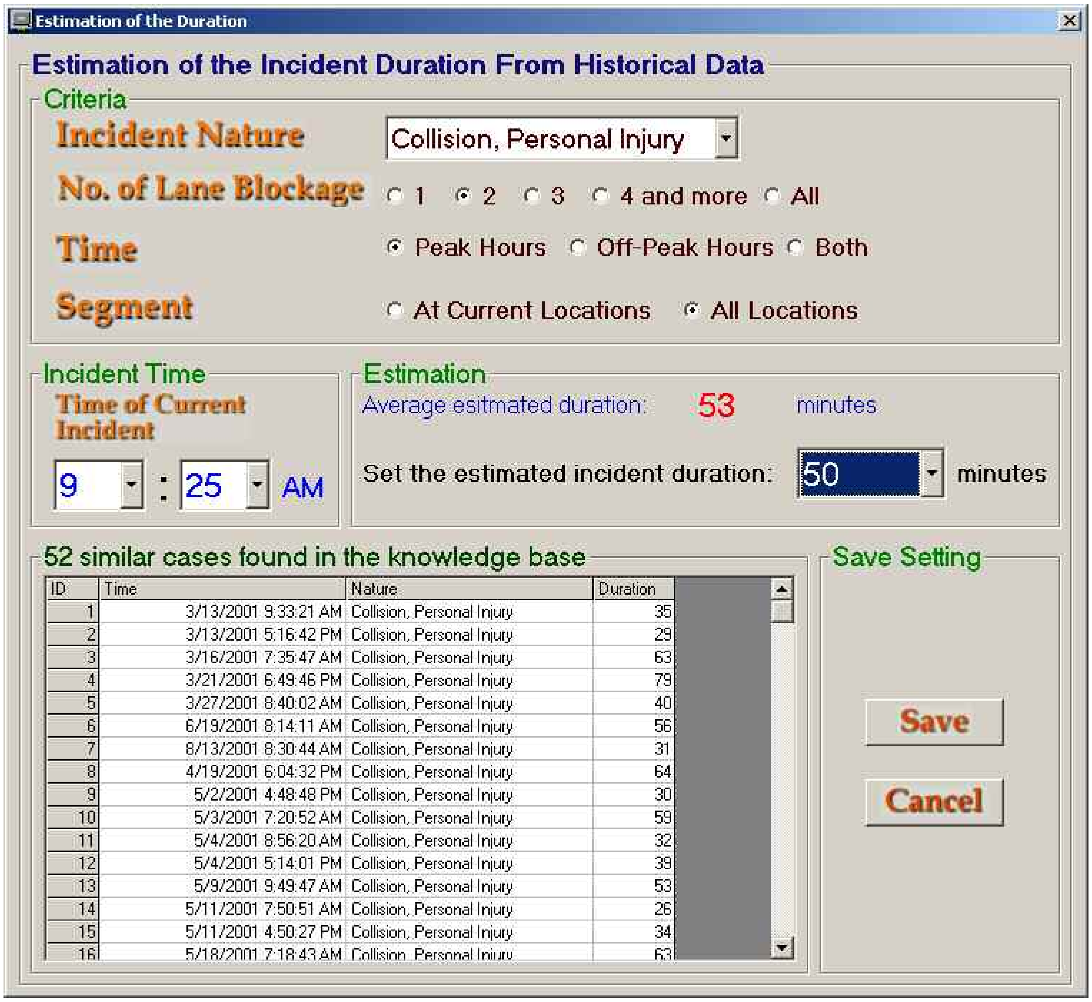
Exit29 (Powder Mill Rd.)

Traffic Direction

IV. What is the approximate duration of incident and for simulation?

The operator will first input the estimated incident duration, using the knowledge-base module and prediction module (see Figure 7-7). Then the operator will input the desired duration of the simulation (see Figure 7-8). Figure 7-7, illustrates that knowledge-base module will display all similar incident cases based on the user-defined criteria.

Figure 7-7 The interface for users to input estimated incident duration



Incident Nature: Collision, Personal Injury

No. of Lane Blockage: ○ 1 ● 2 ○ 3 ○ 4 and more ○ All

Time: ● Peak Hours ○ Off-Peak Hours ○ Both

Segment: ○ At Current Locations ● All Locations

Time of Current Incident: 9 : 25 AM

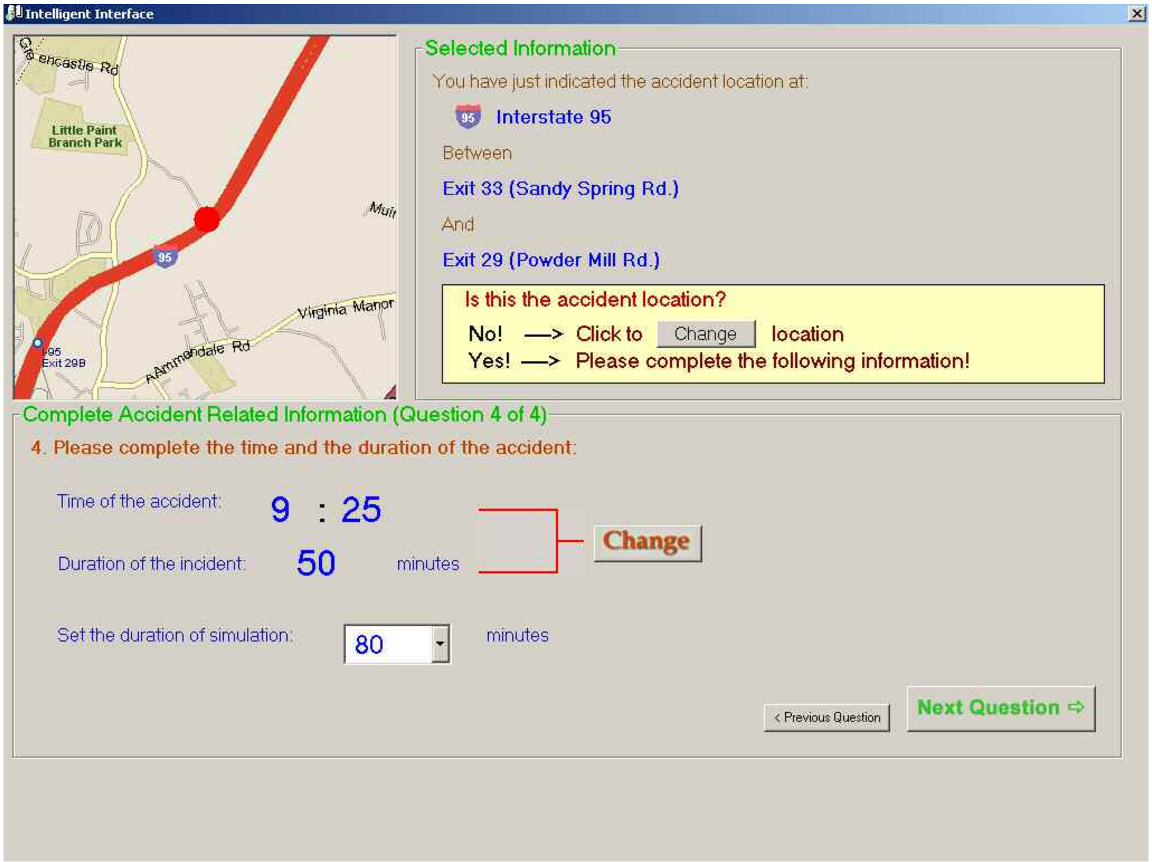
Average esitmated duration: 53 minutes

Set the estimated incident duration: 50 minutes

52 similar cases found in the knowledge base

ID	Time	Nature	Duration
1	3/13/2001 9:33:21 AM	Collision, Personal Injury	35
2	3/13/2001 5:16:42 PM	Collision, Personal Injury	29
3	3/16/2001 7:35:47 AM	Collision, Personal Injury	63
4	3/21/2001 6:49:46 PM	Collision, Personal Injury	79
5	3/27/2001 8:40:02 AM	Collision, Personal Injury	40
6	6/19/2001 8:14:11 AM	Collision, Personal Injury	56
7	8/13/2001 8:30:44 AM	Collision, Personal Injury	31
8	4/19/2001 6:04:32 PM	Collision, Personal Injury	64
9	5/2/2001 4:48:48 PM	Collision, Personal Injury	30
10	5/3/2001 7:20:52 AM	Collision, Personal Injury	59
11	5/4/2001 8:56:20 AM	Collision, Personal Injury	32
12	5/4/2001 5:14:01 PM	Collision, Personal Injury	39
13	5/9/2001 9:49:47 AM	Collision, Personal Injury	53
14	5/11/2001 7:50:51 AM	Collision, Personal Injury	26
15	5/11/2001 4:50:27 PM	Collision, Personal Injury	34
16	5/18/2001 7:18:43 AM	Collision, Personal Injury	63

Figure 7-8 The interface for users to input the desired duration of simulation.



Selected Information

You have just indicated the accident location at:

95 Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Complete Accident Related Information (Question 4 of 4)

4. Please complete the time and the duration of the accident:

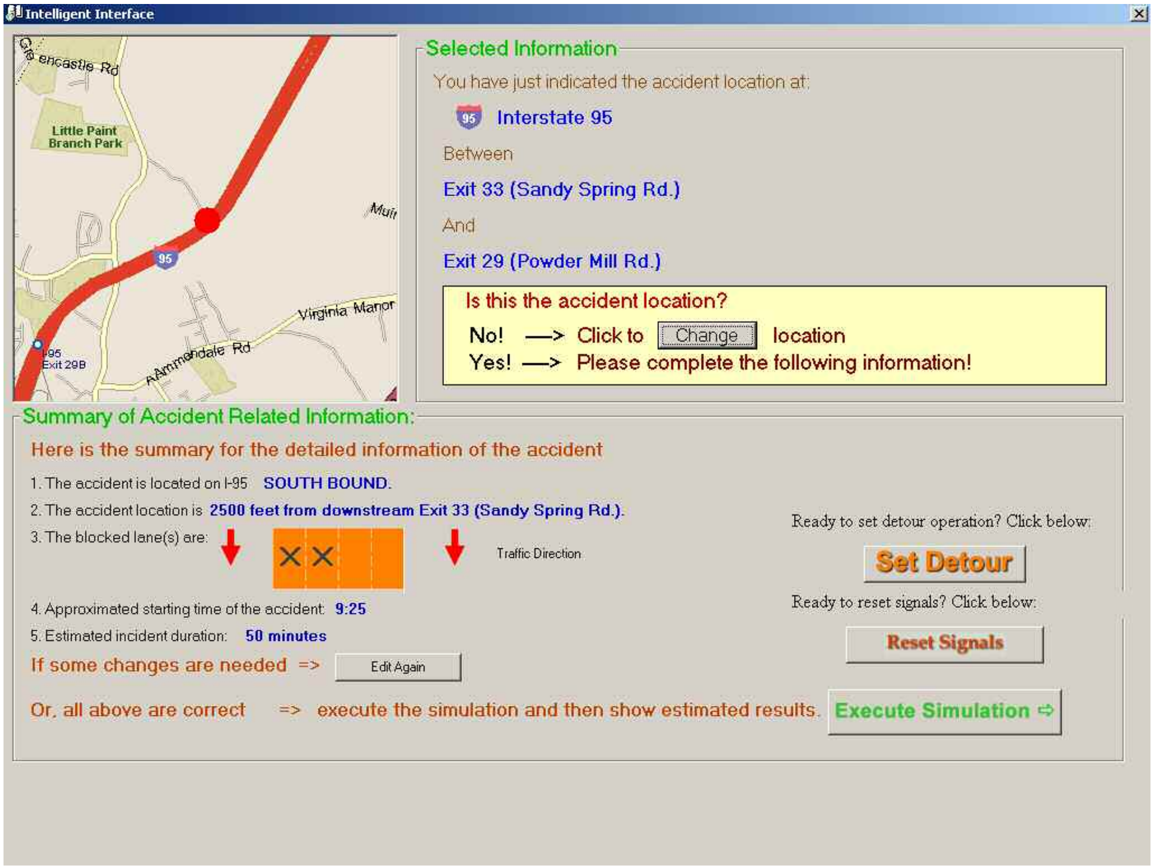
Time of the accident: 9 : 25

Duration of the incident: 50 minutes

Set the duration of simulation: 80 minutes

Step 4: Review the summarized information for the reported incident.

Figure 7-9 The interface for users to review the summarized incident information



Selected Information

You have just indicated the accident location at:

Interstate 95

Between

Exit 33 (Sandy Spring Rd.)

And

Exit 29 (Powder Mill Rd.)

Is this the accident location?

No! —> Click to Change location

Yes! —> Please complete the following information!

Summary of Accident Related Information:

Here is the summary for the detailed information of the accident

1. The accident is located on I-95 SOUTH BOUND.
2. The accident location is 2500 feet from downstream Exit 33 (Sandy Spring Rd.).
3. The blocked lane(s) are: ✕ ✕ Traffic Direction
4. Approximated starting time of the accident: 9:25
5. Estimated incident duration: 50 minutes

If some changes are needed => Edit Again

Or, all above are correct => execute the simulation and then show estimated results. Execute Simulation ⇨

Ready to set detour operation? Click below: Set Detour

Ready to reset signals? Click below: Reset Signals

Step 5: Execute the simulation.

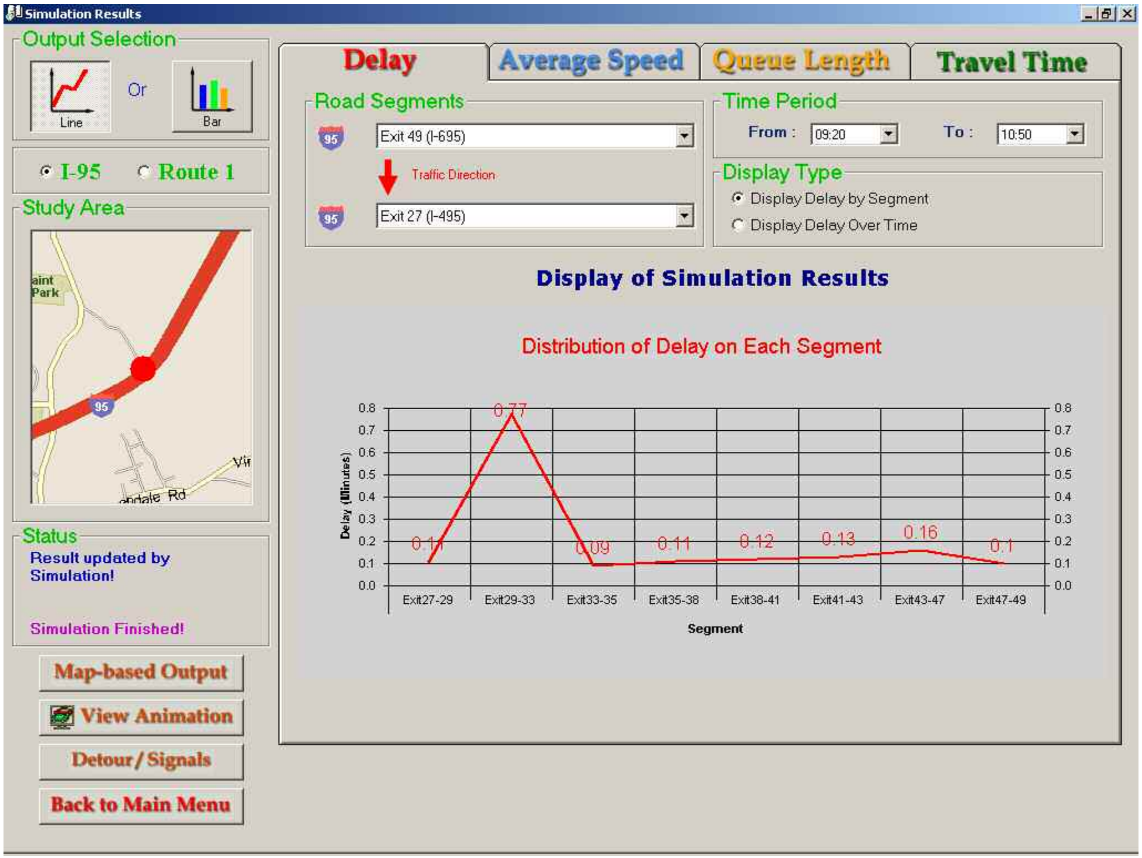
The system will obtain the detector data first (see Figure 7-10), and then execute the simulation.

Figure 7-10 A snapshot of the system when obtaining on-line detector data

Retreiving data from on-line detectors ...

Step 6: View chart-based (see Figure 7-11) and map-based (see Figure 7-12) outputs.

Figure 7-11 Delay tab in the four categories of the chart-based output



Simulation Results

Output Selection: Line Or Bar

● I-95 ○ Route 1

Road Segments: Exit 49 (I-695) → Exit 27 (I-495)

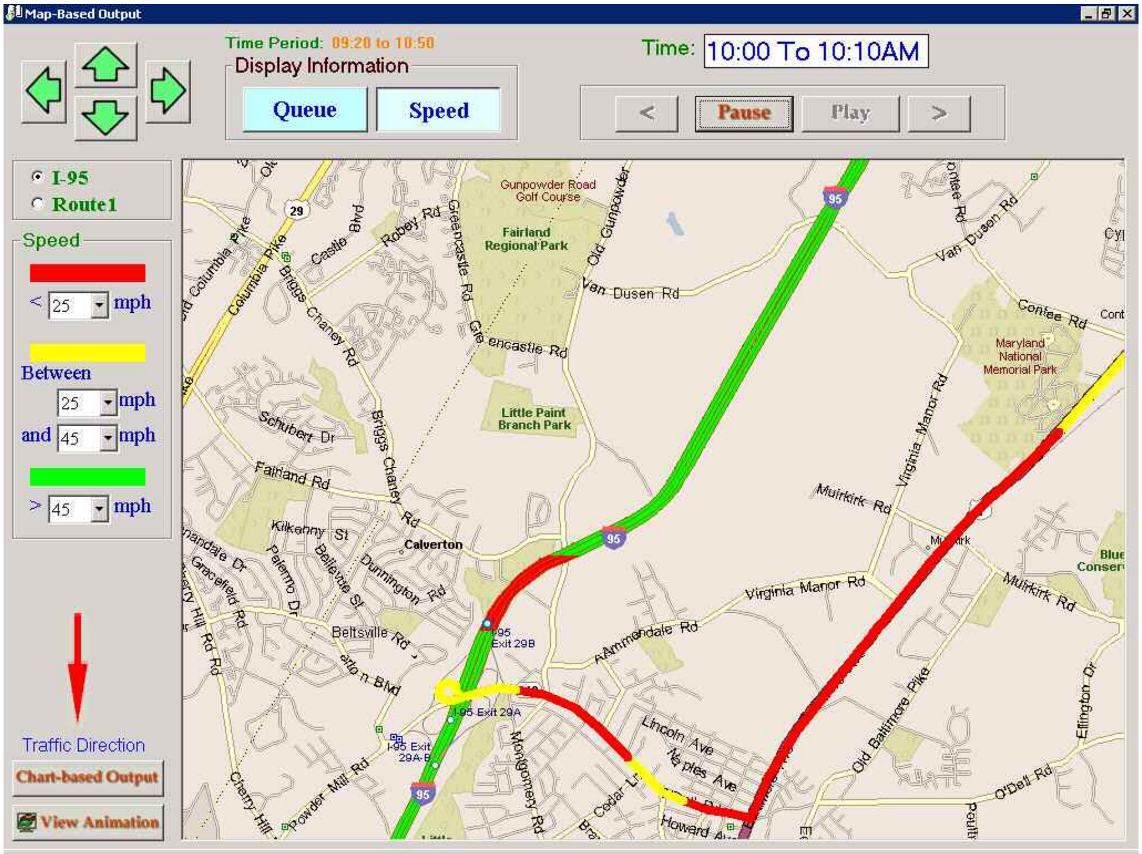
Time Period: From: 09:20 To: 10:50

Display Type:
● Display Delay by Segment
○ Display Delay Over Time

Status: Result updated by Simulation!

Simulation Finished!

Figure 7-12 The map-based output of the average speed on both I-95 and the detour route



Time Period: 09:20 to 10:50

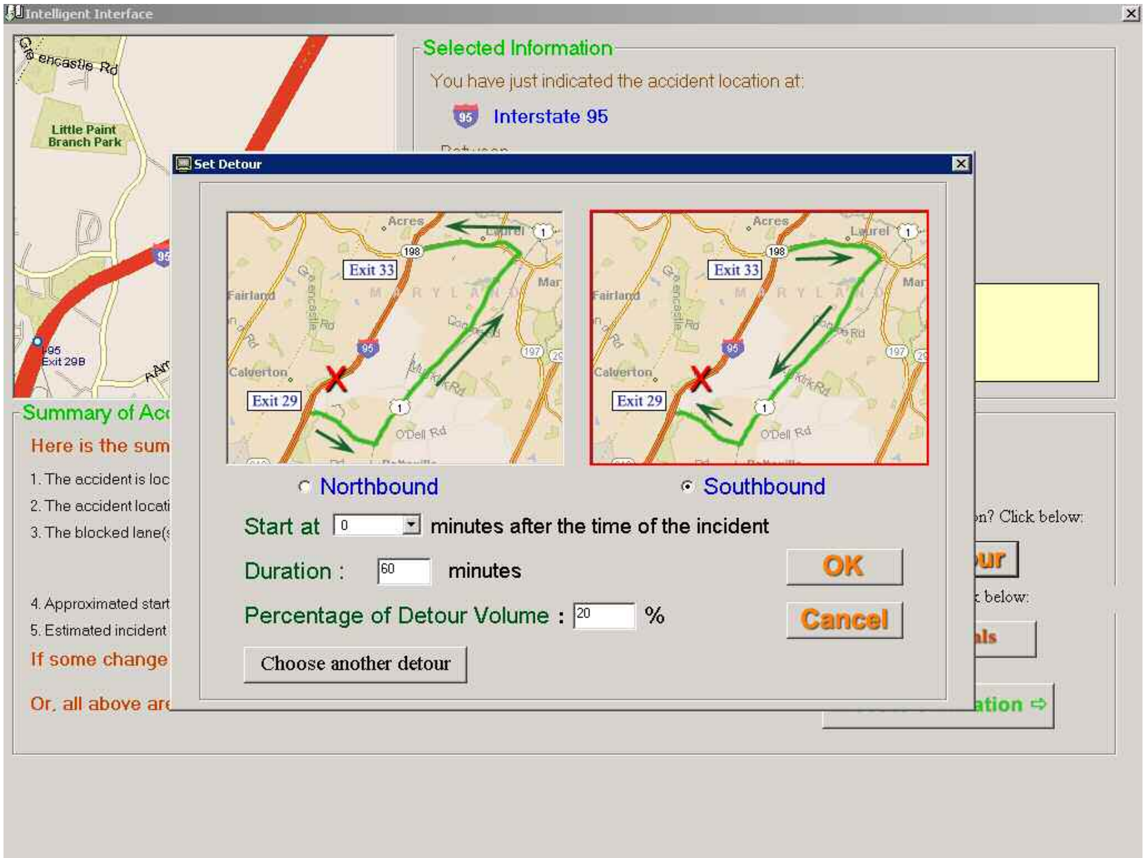
Time: 10:00 To 10:10AM

● I-95
○ Route1

Speed
🟥 < 25 mph
🟨 Between 25 mph and 45 mph
🟩 > 45 mph

Step 7: Perform the detour operation (see Figure 7-13) and change signal phases on detour routes (see Figure 7-14 and Figure 7-15).

Figure 7-13 The input interface for the detour operation



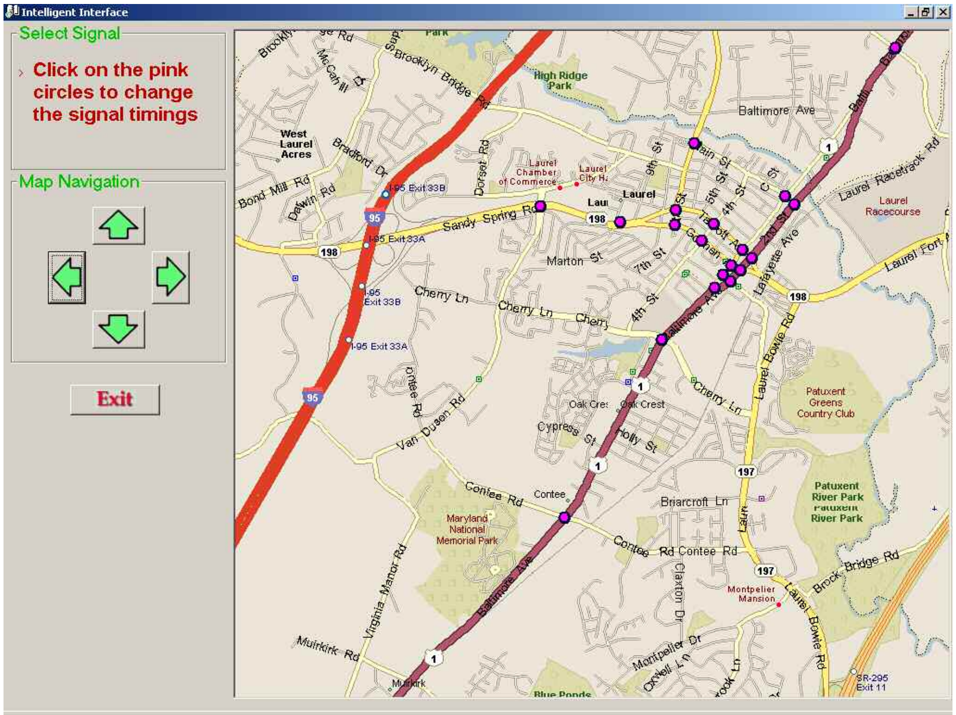
○ Northbound ● Southbound

Start at 0 minutes after the time of the incident

Duration : 60 minutes

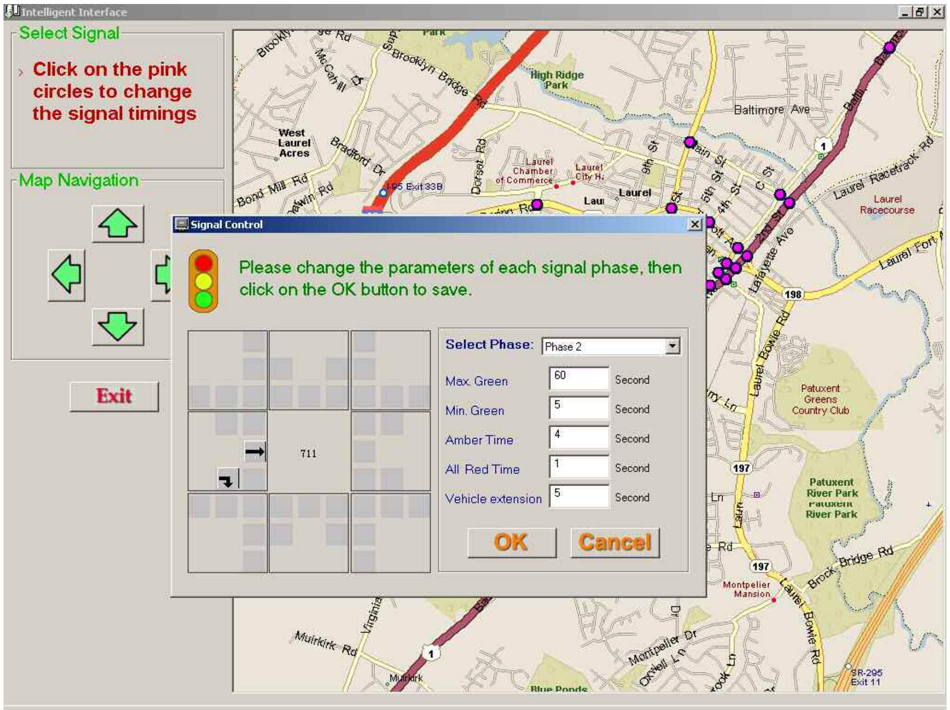
Percentage of Detour Volume : 20 %

Figure 7-14 The interface for selecting the signal



Click on the pink circles to change the signal timings

Figure 7-15 The interface for the change of the signal timing



Click on the pink circles to change the signal timings

Please change the parameters of each signal phase, then click on the OK button to save.

Select Phase: Phase 2

Max. Green 60 Second

Min. Green 5 Second

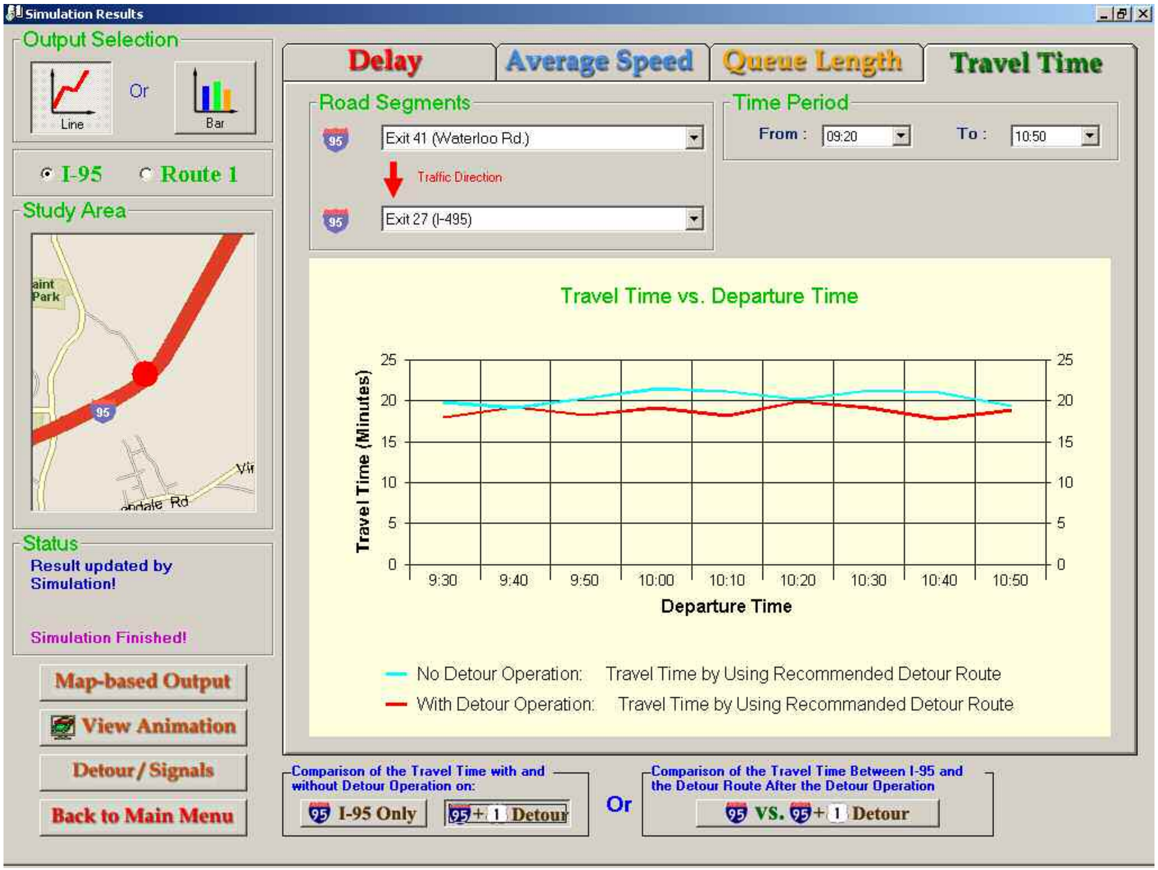
Amber Time 4 Second

All Red Time 1 Second

Vehicle extension 5 Second

Step 8: Perform simulation again and evaluate the effectiveness of the detour operation (see Figure 7-16).

Figure 7-16 Comparison of the travel time vs. departure time via the detour route before and after the detour operation



Simulation Results

● I-95 ○ Route 1

Road Segments: Exit 41 (Waterloo Rd.) → Exit 27 (I-495)

Time Period From : 09:20 To : 10:50

Status: Result updated by Simulation!

Simulation Finished!

7.2. Future Enhancements

To improve performance and satisfy the critical requirements of real-time traffic management, the I-95/Route-1 simulator still requires further improvements. Recommendations for future enhancements are as follows:

- Integrate the proposed system with an optimization module that can assist traffic control operators in selecting the most effective plans (e.g. ramp metering and integrated freeway/surface street control).
- Develop a web interface for the simulator to allow the execution and display of results via the Internet at multiple workstations.
- Improve the system by incorporating more simulation servers to allow the execution of multiple scenarios at the same time.
- Collect more quality data and employ an integrated neural network/rule-based model to estimate durations for categories of incidents that cannot be tackled at the current stage.
- Build in advanced procedures that allow users to adopt incomplete historical and real-time data from user input and detectors, which can be used for system input or data validation.

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