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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

Integration of Detector Data, Archive Information, and Simulation for Reliable Estimation of Travel Time During Non-recurrent Congestion – An Application for the I-270 Corridor –

University of Maryland, College Park

MD-04-SP308B4J
FINAL REPORT

OCTOBER 2004

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16. Abstract

This study presents an Integrated Traffic Information and Simulation System (ITIS), including a detailed description of its principal components and their interrelations, the main functions embedded in each technical module, and key algorithms employed to verify users needs and to perform the required estimation. The proposed ITIS system offers an effective tool for MSHA engineer/planners to take full advantage of information available from on-line detectors, archive data, and simulation results for estimating travel times during non-recurrent and recurrent congestion patterns. With those embedded functions and customized interfaces, the ITIS system can also be used for work zone planning and operational analysis, and for assessment of various traffic control strategies. The developed ITIS with its extensive information can also serve as an intelligent database system that can help potential users identify the data needs based on the requested applications, and perform the best estimation with available data.

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Chapter 1
Introduction

1.1 Background

Due to the ever-increasing travel demand on major commuting corridors and the uncertainty of potential traffic conditions, most highway agencies in recent years have faced mounting pressures to provide travel time information, especially during non-recurrent congestion. However, unless the commuting corridor has been deployed with extensive surveillance sensors, it is quite difficult for responsible highway agencies to project traffic conditions to a level that is sufficiently reliable for commuters to make en-route or pre-trip travel decisions.

This study proposes to focus on travel time prediction issues on Maryland state highway networks that have limited traffic surveillance systems due to diminishing resources at both the state and federal levels, which have in the past, prevented Maryland State Highway Administration (MSHA) from investing in these types of expensive yet necessary systems. A creative alternative presented in this study is to develop a simulation-based system for real-time prediction of traffic conditions. The proposed system will integrate on-line detector and archived information with a traffic simulator, which would be designed specifically for main freeway corridors such as I-270. The system would be capable of predicting travel time and delay information during non-recurrent traffic congestion.

As part of the real-time traffic prediction system, this study will also develop an integrated traffic information database that will be capable of integrating on-line detector data, archived traffic volume data, and recorded incident impacts. With such information traffic engineers can calibrate and revise key parameters on a consistent basis prior to the execution of simulation and its associated functions. For example, a traffic simulator's projected results will be updated on a consistent basis over time as data from on-line sensors or real-time field operating reports become available. The proposed simulation-based traffic prediction system with all its unique and interchangeable functions will offer

MSHA a cost-effective alternative to provide reliable traffic information to the general public. It will also be able to substantially reduce most expenses associated with the deployment, operations, and maintenance of traffic surveillance systems.

1.2 Research Objectives

The primary objective of this study is to develop an intelligent simulation-based system that can effectively integrate all available information and provide a best estimate of travel time and delay to both control center operators and commuters during non-recurrent congestion. The proposed Integrated Traffic Information Simulation (ITIS) system consists of the following two principal components:

- A database module that efficiently integrates information from previous incident management reports and various available on-line as well as off-line data; and
- A simulation-based module to perform a robust estimation of the time-varying travel times and delays during both recurrent and non-recurrent congestion.

A traffic control center using this proposed system will be capable of informing both en route or pre-trip commuters regarding the duration of a detected incident, and its impact on various segments of the commuting corridor during the incident period. The control center operator can also use the predicted traffic impacts to assess potential incident management plans, such as detour operations, and displays on variable message signs.

1.3 Research Methodology

Based on the information available in the I-270/MD 355 simulator, this study conducted its primary research activities along the following two lines: (1) extending the simulation data set to a generalized traffic information database with an intelligent interface to facilitate its applications, and (2) expanding the simulation functions and its output for management of both recurrent and non-recurrent traffic congestion. All main research activities and procedures along each of these development lines are summarized on the following page.

- *Extending the simulation dataset to a generalized information base*

The primary purpose for this generalized information base is to ensure that potential users can conveniently take advantage of all available data associated with the specific highway facilities such as geometric features, traffic conditions, incident impacts, and control devices. The developed information base should also allow users to update the system with the most recent data available from either on-line or off-line sources. Its development procedures include:

- Identifying information associated with the target highway facilities from different MSHA departments. Examples of such information are the time and date of collected traffic volume, travel time, traffic flow speed, delay, and incident impacts.
- Classifying all available information on a link-by-link basis into the following categories: volume, speed, signal, travel time, incidents, geometry, and detectors.
- Developing an intelligent interface mechanism to facilitate the import of updated data from either on-line or archived information sources.
- Constructing an intelligent search engine that will guide users in identifying and using the information available in the generalized information base.

- *Expanding the simulation functions for traffic management*

Research activities conducted along this research line will assist MSHA staff in using a variety of functions provided by the I-270/MD 355 simulator for travel time estimation. The primary focus is to expand the existing simulator to an advanced traffic management module that can automatically identify the data needs, construct the required input data file, and select the appropriate tool for analysis, based on the target applications requested by the users. More specifically, the entire study on this regard consists of the following activities:

- Construction of an intelligent mechanism to assess the data needs based on the target application specified by the user.

- Designing an automatic estimation mechanism to estimate data that is not available in the information base but essential for the requested applications.
- Programming travel time estimation algorithms with historical data and statistical methods.
- Automation of the volume update process from available on-line surveillance sensors.
- Development of an automated function to generate the input data file for on-line and/or off-line simulation analysis; and
- Customizing the simulation output for travel time estimation under either recurrent or non-recurrent traffic congestion.

To ensure the quality of available information, this study develops a set of detecting procedures that can automatically filter and remove any noise or variance embedded in the off-line or on-line traffic related data prior to the use of any applications. This is an important task since most freeways in Maryland have a limited number of surveillance sensors, and estimating the missing data at those locations is critical. The developed algorithms for estimating missing data can function effectively only if those available on-line and archived data are adequately reliable to serve as the estimation baseline.

In order to contend with the complexity of travel time estimation during non-recurrent congestion, this study also constructed a historical incident database for the I-270/MD 355 simulator based on the MSHA CHART-II (Coordinated Highways Action Response Team) system. From such an incident database, traffic control operators can estimate the required duration for clearing a detected incident based on prior operational experience at the same or similar locations during the same time of a day. A statistical model has also been developed for predicting the duration of those incidents, which have previously not been collected in the historical database.

Since the primary focus of this study is to provide travel time information, the customized simulation output includes off-line estimation of travel time during recurrent congestion, on-line prediction of incident impacts and the resulting delay. A user-friendly interface to facilitate the evaluation of various candidate controls or detour plans during

the response and management of major incidents was also included in the simulation output development.

1.4 Report Organization

Since the primary product used in this study is a software program that is readily available for on-line and off-line applications, this report serves mainly as a supplemental documentation of key research efforts, and not at all for detailed description of development activities. This report is organized into seven chapters, covering mainly the overall system framework, input and output modules, estimation algorithms, and example applications. A brief description of each chapter is presented in sequence below.

Chapter 2 illustrates potential applications of the proposed ITIS system and its relationship with existing MSHA information databases. It provides an overview of the entire software program that includes input interface, an integrated database, and the simulation application module. The interrelationships between all principal components within and between each system module and the operating procedures for off-line and on-line applications also constitute the core of this chapter.

Chapter 3 focuses on describing the functions and the operating logic of an information input module, which is designed to facilitate users in gathering information from various sources, including on-line detectors, archived data, and available incident reports from MSHA CHART-II system. This chapter also discusses the key features of such an intelligent interface and its principal functions for use with either off-line or real-time applications, such as:

- Integrating on-line detector data with archived traffic information;
- Receiving data from various sources;
- Interacting with CHART database, and on-line traffic sensors, and;
- Offering guidance for potential users to select the most effective method in travel time estimation.

Chapter 4 is devoted to introducing the Information Query Module (IQM), which is designed to assist users in taking full advantage of all information available in the ITIS System and to support a variety of traffic planning or operational related work. Examples of applications include:

- Preparation of traffic condition reports for a target highway segments (e.g., speed, delay, volume);
- Analyzing traffic safety improvements (e.g., incident frequency, distribution, nature);
- Planning and comparing work zone operational plans;
- On-line and/or off-line estimation of traffic conditions under both recurrent; and non-recurrent congestion;
- Evaluation of incident impacts and;
- Data query functions designed to check the availability of data in response to a requested application.

Chapter 5 presents one of the most critical functions offered by the system--automatic estimation of volume for locations without detector stations or with insufficient archived data. The function for missing data estimation is designed in response to the fact that many freeway corridors in Maryland do not have a sufficient number of traffic sensors for constructing a complete input dataset for either on-line or off-line simulation analysis. A user cannot perform a variety of traffic management functions with the embedded simulator if the required input dataset is incomplete.

The entire estimation function is supported with two embedded algorithms. The level-1 algorithm is designed to estimate those missing volumes with all available on-line detector data, which are assumed to have the identical quality. The level-2 algorithm is developed for a generalized scenario where both on-line detector data and archived data can be integrated for estimating the volume of those locations without information. Numerical examples for illustrating the estimation algorithms have also been included in this chapter.

Chapter 6 provides some example applications of the developed ITIS system's advanced traffic management functions, including travel time estimation for day-to-day recurrent congestion; analysis of traffic conditions during the response and operations of a detected incident; and evaluation of detour strategies during severe incidents. This chapter will also discuss how to use the available functions in planning and assessing work zone operational strategies. As the developed ITIS system contains a variety of input/output and application functions, this chapter presents only major features. All

other similar applications and system features are available in the software developed for this study.

Chapter 7 summarizes research findings and development experience for this study, including some technical issues associated with statewide data collection and inventory. Recommendations for field implementation of the system developed from this study along with the development of some supplemental subsystems will also be reported this chapter.

Chapter 2

Description of the System Framework

2.1 System Applications

This project focuses on developing an Integrated Traffic Information and Simulation system (ITIS) for both off-line and on-line estimation of travel time and traffic conditions under recurrent and non-recurrent congestion patterns. The ITIS system, developed on the basis of the I-270/MD 355 traffic simulator, features a customized user interface, an extensive information base, and various intelligent functions that automatically construct the input data and execute the simulation in response to a requested application. For example, the ITIS system, as illustrated in Figure 2-1, can function like a geographical information system (GIS) and map the geometric features of a specific freeway facility with available traffic data and surveillance detector information.

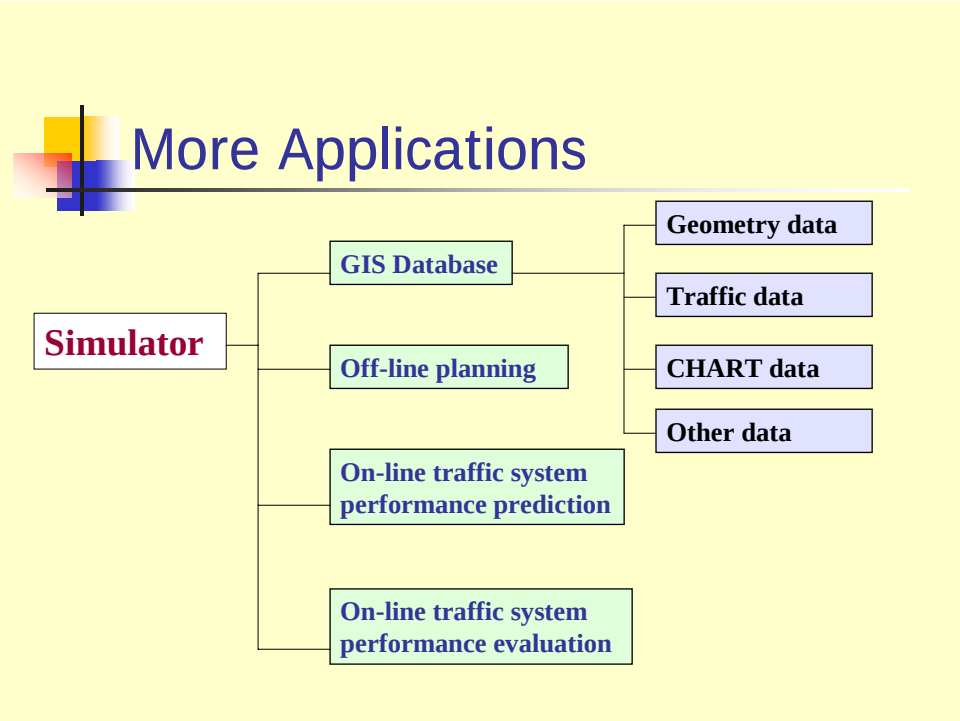


Figure 2-1: Potential Applications with the Proposed Integrated Traffic Information/Simulation System

By connecting to the MSHA CHART performance database, this system can also provide incident distribution data along the freeway using either location or incident data. The operational duration for clearing various types of past incidents under different traffic conditions along the entire freeway segment is also available in the ITIS information base.

With the customized interface module to assist users in identifying available information, the ITIS can help traffic engineers/planners perform a variety of planning activities, such as:

- Evaluating candidate work zone plans;
- Estimating the maximum queue length under various control strategies (e.g., ramp metering);
- Assessing the effectiveness of detour operations during severe incidents, and;
- Selecting evacuation plans during special events or emergencies.

The proposed ITIS system is also capable of directly updating traffic volume and speed data from available surveillance sensors, and perform on-line simulation to project traffic conditions such as delay, travel time, and queue length during both recurrent congestion and incidents. Since traffic sensors have only been deployed on limited segments of most MSHA freeways, this study has developed a special program for estimating missing data from existing archived and available sensor information. This is to ensure that the ITIS system, constructed from both on-line and estimated information, can have a complete data set for analyzing the target application.

The required simulation time for the I-270/MD 355 corridor is about 10 percent of the actual duration (it takes 6 minutes to simulate one hour). Thus, one can use the simulator in a real-time evaluation of various control or detouring strategies during severe traffic incidents, such as after special events like football games. The traffic application module in the ITIS system can also interact with external supplemental modules to perform statistical analyses or system optimizations, based on the simulation output.

2.2 System Structure

Figure 2-2 presents the main structure, key functions, and the interrelationship among principal components of the proposed ITIS system, which is expanded mainly from the input dataset and simulation functions of the traffic simulator. The entire ITIS system consists of three principal components: input interface, Integrated Database (ID), and a simulation application module.

The input interface is designed for the ITIS system to receive various types of data associated with the target freeway facility from different on-line or off-line sources. Such information can be imported directly from the data sources to the ITIS database, or inputted manually through an Internet interface or a specially designed input function. Examples of data types to be stored in the ITIS system through the Input Interface include: volume, speed, signal phasing and settings, incidents, geometric features, control hardware and surveillance sensors, and general operational guidelines (see Figure 2-3).

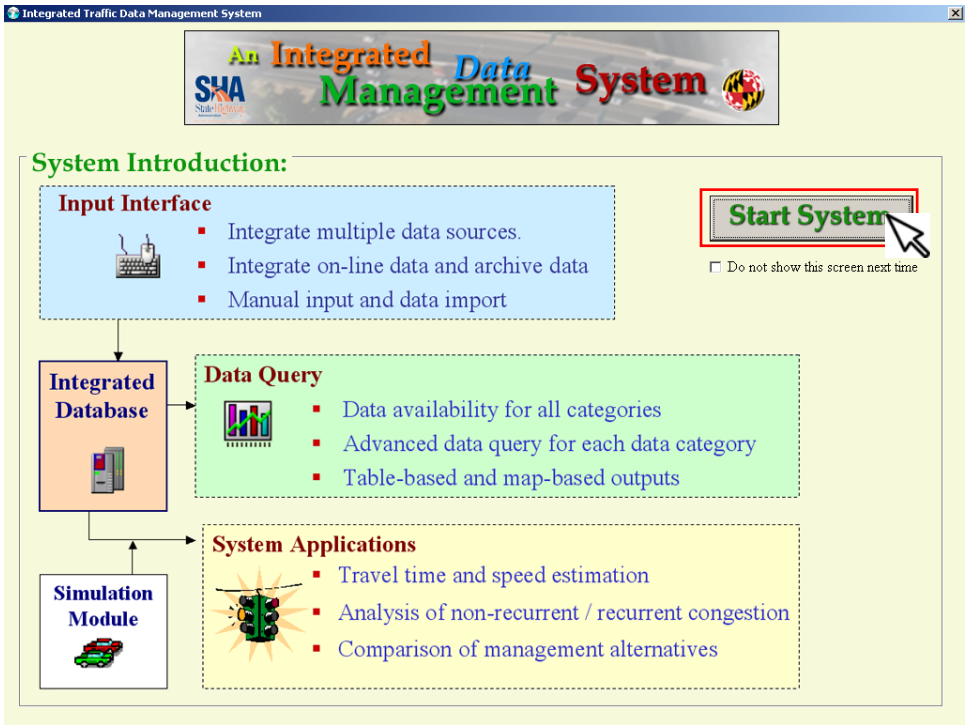


Figure 2-2: Principal Components of the Integrated Traffic Information/Simulation System

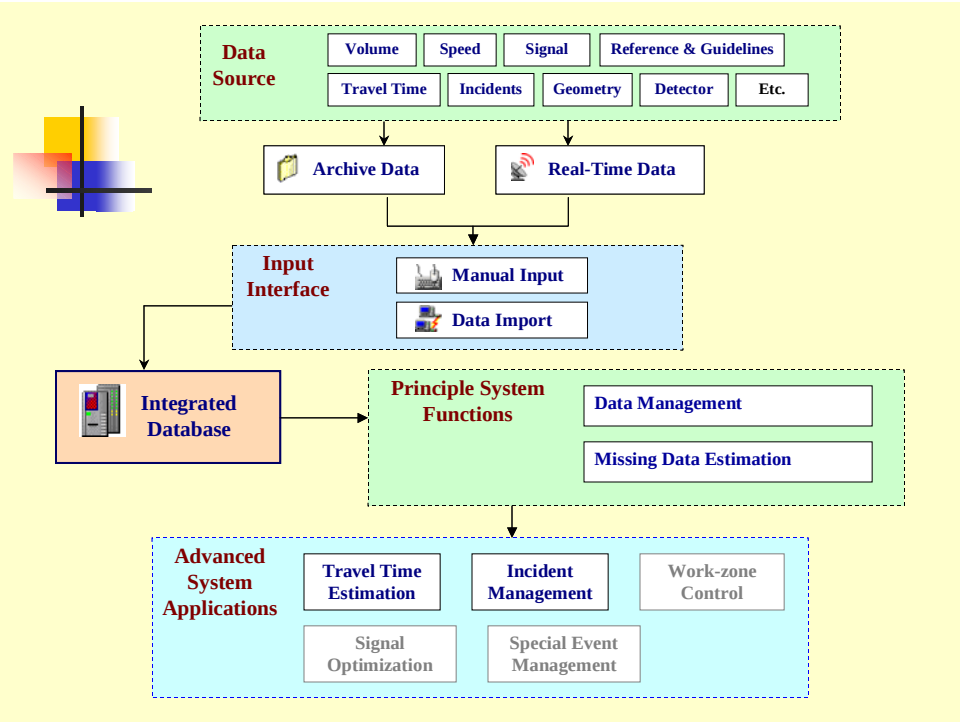


Figure 2-3: Interrelationship Among Principal System components and Key Functions of the ITIS system

The second primary component of the ITIS system is an Integrated Database (ID) that organizes a variety of data transported through the Input Interface, and responds to queries as well as questions raised by the users. The proposed ID has the following distinct features:

- *Assists users in analyzing available data*

Different from most database systems, the proposed ID is capable of guiding users to select proper data for references, or in constructing a required input dataset for simulation analysis. For example, in response to an inquiry of the approximate duration for clearing a detected incident, the ID will first display all incidents of similar nature at the same location over the past time period specified by the users (i.e. past 6 months), and will then display an estimated clearance duration based on the available data. The user can take the average duration of all displayed prior incidents, or compare his/her estimated duration with that provided by the ID to approximate the required clearance duration for a detected incident.

- *Estimate missing data*

This feature, using advanced statistical and traffic flow models, is designed to provide an estimate of the information requested by the users yet not available in the existing database. For instance, if requested travel time data over a freeway segment is not available in the database, the ID can provide its best estimate for the user based on the volumes of the neighboring segments and historical travel times during the same time period. A detailed description of the estimation algorithm is available in Chapter 5.

- *Automatic construction of a required dataset for simulation analysis*

Due to the extensive data needs for simulation analyses, the ITIS may not have sufficient data needed for analysis. Thus, this feature is designed to assist users in generating the dataset for required simulation analysis, including identifying missing data, activating the statistical module for missing data estimation, checking the data consistency, and executing the simulation program. For example, to assess the impacts of a proposed work zone operation, the ID can automatically estimate the volume for those ramps without detectors or historical data, and construct a dataset based on both actual and estimated volume to activate the simulation analysis. In addition, the system also provides a variety of formats for output analysis, including statistical summary, tables, and map-based displays.

The third primary component of the ITIS system is an Advanced Traffic Application (ATA) module that is based mainly on the embedded traffic simulator. This specially designed module has the following unique features to facilitate the ITIS system applications:

- Automatic structuring of data provided by the ID and the interface component needed to execute the simulation analysis.
- Custom information generated from the simulation output into a number of categories, each designed specifically for a target type of application.
- Effective interacting with other supplemental modules for statistical analysis or system optimization such as estimating incident duration, computing ramp metering rates, and optimizing signal phasing plans during detour operations.
- Offering efficient and flexible computing for use in both off-line planning analyses and real-time evaluation of traffic control or operational strategies.

The core design logic of the ATA module is to employ an interactive graphical interface to guide potential users step-by-step in using the simulation results. With the customized input procedures and output analyses, users can circumvent the complex simulation operating process and directly use the simulation results for target applications. The ITIS at its current phase has offered customized input-output modules for the following types of applications: work zone impact analysis, missing volume estimation, off-line travel time and traffic impact analysis; and real-time projection of travel time and detour strategies during non-recurrent congestion. Evaluation of signal optimization and evacuation plans for special events will be included in subsequent studies.

2.3 On-line Operational Feature

In order to effectively use simulation for on-line applications, the following two major barriers must be addressed: computing efficiency and data deficiency. The proposed ITIS system has successfully achieved computing efficient real-time applications by replacing extensive and detailed simulation results with customized outputs that include critical information of the target analyses. The simulation speed for the current ITIS system with the most recent computing hardware is around 10 percent of the simulated duration. For example, it will take about 6 minutes to simulate the I-270/MD 355 corridor for one congested hour.

With respect to the data deficiency due to the lack of sufficient sensors deployed on freeway ramps and main segments, the proposed ITIS has a supplemental module that can automatically provide the best estimate of volume or travel time data for those locations without sensors. A detailed description of such algorithms for estimating missing data is available in Chapter 5. Users can follow the graphical instructions to follow the simulation analysis after all missing data has been estimated by the embedded module.

Figure 2-4 illustrates the on-line application process, which includes the following key steps:

1. Identify the data needs for applications submitted via Internet or manual input.

2. Conduct a data availability check and activate the module to estimate missing data if necessary.
3. Construct the input file by integrating available data from on-line sources, archived databases, and estimated results from the ITIS supplemental components.
4. Execute the simulation and provide the projected traffic conditions based on the simulation results.
5. Update the input file with the most recent traffic information from on-line sensors.
6. Re-estimate those missing data items with the available and updated information.
7. Re-execute the simulation analysis to update the projected traffic conditions over a pre-specified time horizon.
8. Repeat Steps 5 to 7 until the entire on-line projection or analysis process is complete.

Since traffic conditions during a non-recurrent or recurrent congestion period may vary one needs to ensure that all such strategies and information scenarios have been properly modeled in the ITIS.

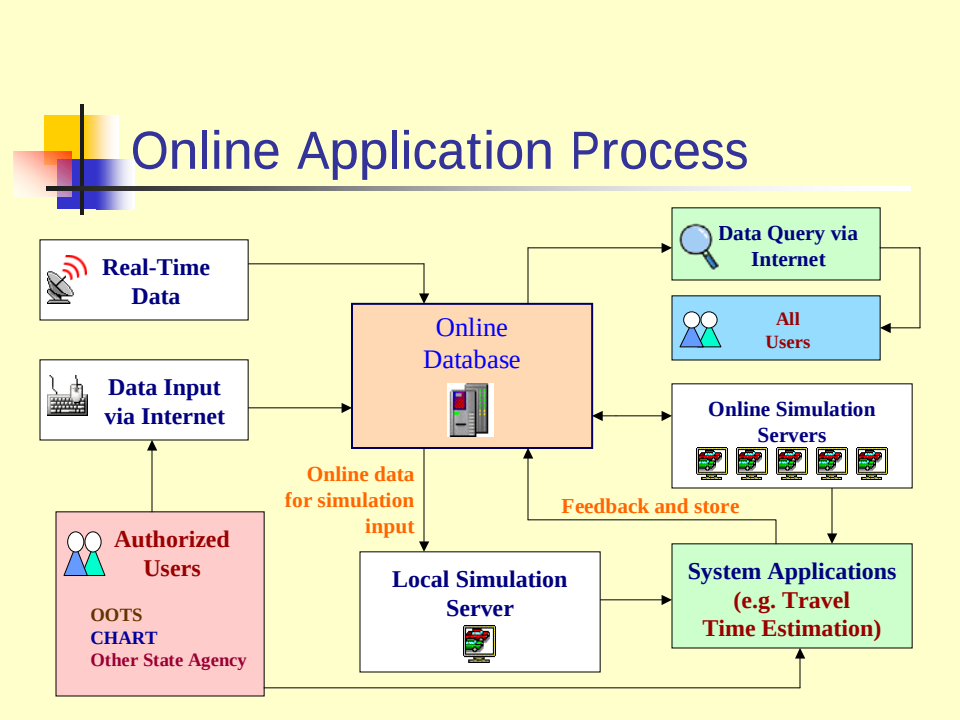


Figure 2-4: A Graphical Illustration of the On-Line Application Process

2.4 Conclusion

Chapter 2 illustrates the potential applications of the proposed ITIS system and its relationship to with the existing information databases in MSHA. It provides an overview of the entire software program that includes input interface, an integrated database, and the simulation application module. The interrelationships between key functions embedded in each system module and the operating procedures for off-line and on-line applications have also been discussed in this chapter. A detailed presentation of each principal module and the algorithm for estimating missing data is available in the ensuing chapters.

Chapter 3
Description of the Information Input Module

3.1 Introduction

This chapter describes the functions and the operational logic of the Information Input Module (IIM), which is designed to assist users in gathering information from various sources, including on-line detectors, archived data, and available incident reports.

The IIM, proposed in response to the needs for both on-line operations and off-line planning, has the following features :

- Integrating on-line detector data with archived traffic information;
- Correlating traffic data with incident locations;
- Receiving data from various sources, including CHART database, and on-line traffic sensors, and;
- Offering an efficient and friendly interface to guide potential users in selecting the most effective method to enrich the database of the ITIS.

With all the above functions, users can conveniently update the following data in the ITIS:

- Traffic volume, for freeway links, interchanges, and intersections;
- Traffic flow speed;
- Traffic occupancy;
- Travel time;
- Detector type, location, and performance, and;
- Incident location, frequency, and related information.

To minimize the learning curve of potential users, the proposed IIM provides the following functions for its applications:

- Map-based navigation;
- Link segment input;
- Interchange data input; and,
- Intersection data input.

Each of these key functions is described, respectively in the following sections.

3.2 Map-Based Navigation Functions

Map navigation functions utilize the GIS design concept that enables users to first, directly identify the location of the target freeway segment or interchange from the map (see Figure 3-1), and then input the related data.

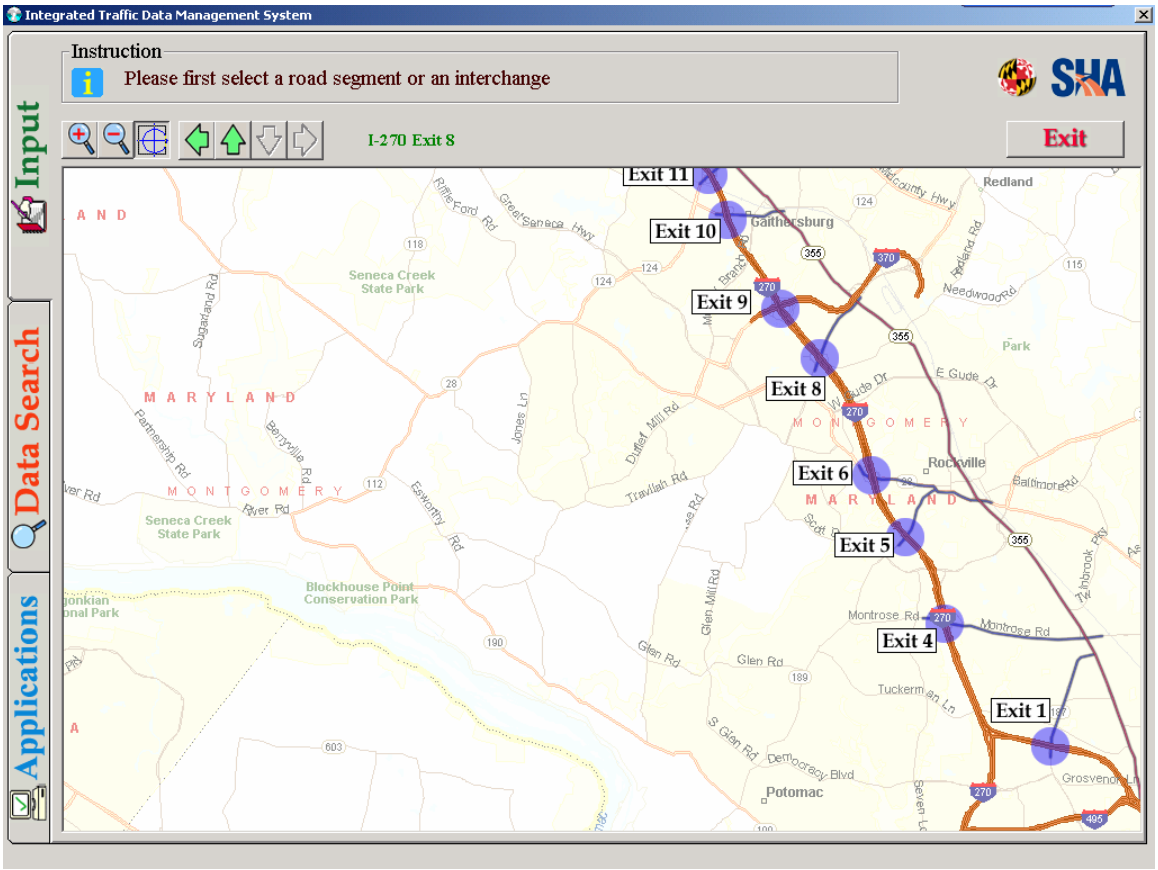


Figure 3-1: Data Input Interface with the Map-based Function

The map navigation functions consist of three components: a toolbar, a map view, and a status bar. Table 3-1 summarizes the list of toolbar icons available for applications.

Table 3-1: A list of toolbar icons

Name	Icon	Function
Zoom in		Use this tool to zoom in.
Zoom out		Use this tool to zoom out.
Select		Use this tool to select a segment or interchange
Left		Use this tool to move to left
Up		Use this tool to move up
Down		Use this tool to move down
Right		Use this tool to move to right

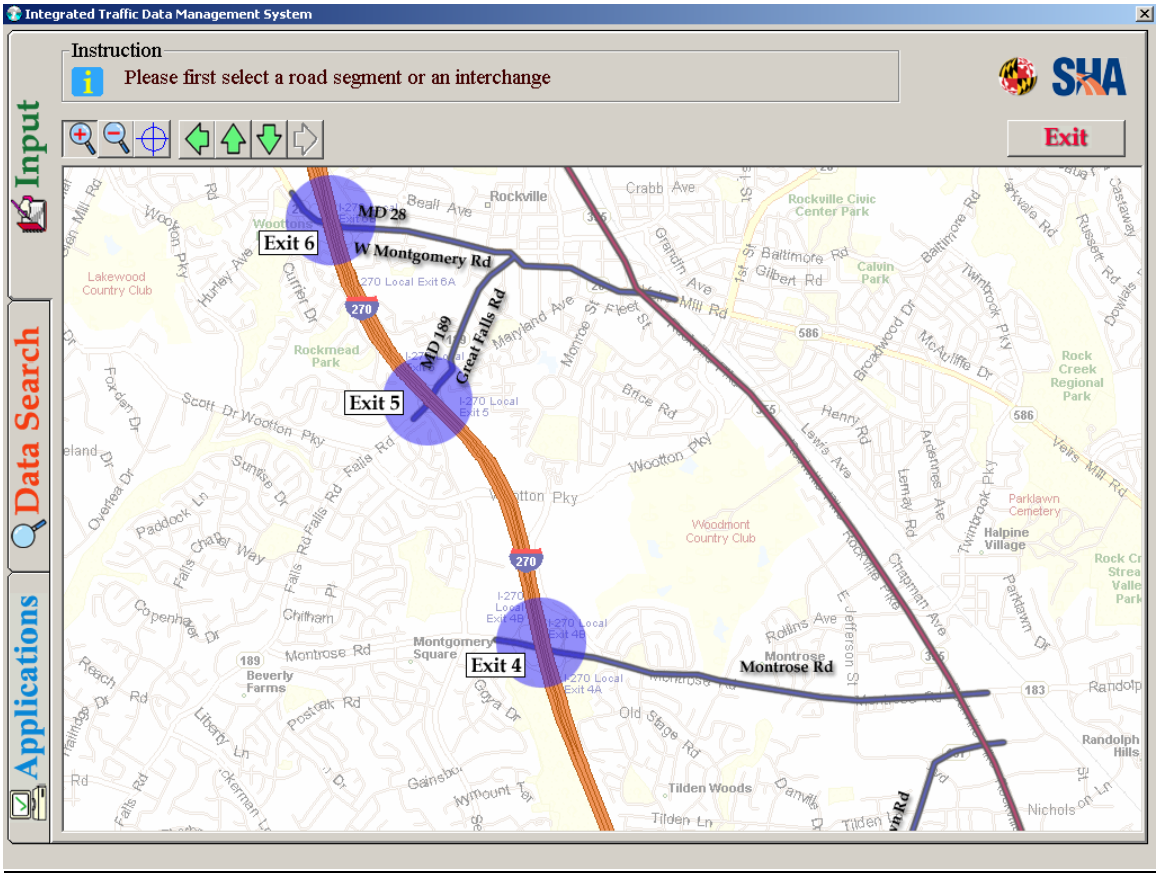


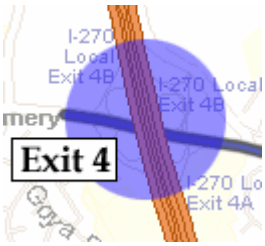
Figure 3-2: An Example of the Map View Provided by Information Input Module

An example of the map view for the I-270 and MD 355 network is displayed in Figure 3-2. Users can use the toolbar tools to zoom in/out of the map view. Such a system will typically show the following graphics:

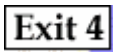
- ***Freeway***

- ***Arterial road***

- ***Interchange***



- ***Exit number***



The status bar provided by IIM is designed to display the following types of messages:

- The information associated with the target segment:

  I-270 Segment from Exit 4 to Exit 5

- The current interchange information:

  I-270 Exit 4

- Indicating no information is available:

  Not Available

3.3 Link Segment Input

The input interface for link segments will automatically pop up if a freeway segment is selected with the map navigation functions (see Figure 3-3).

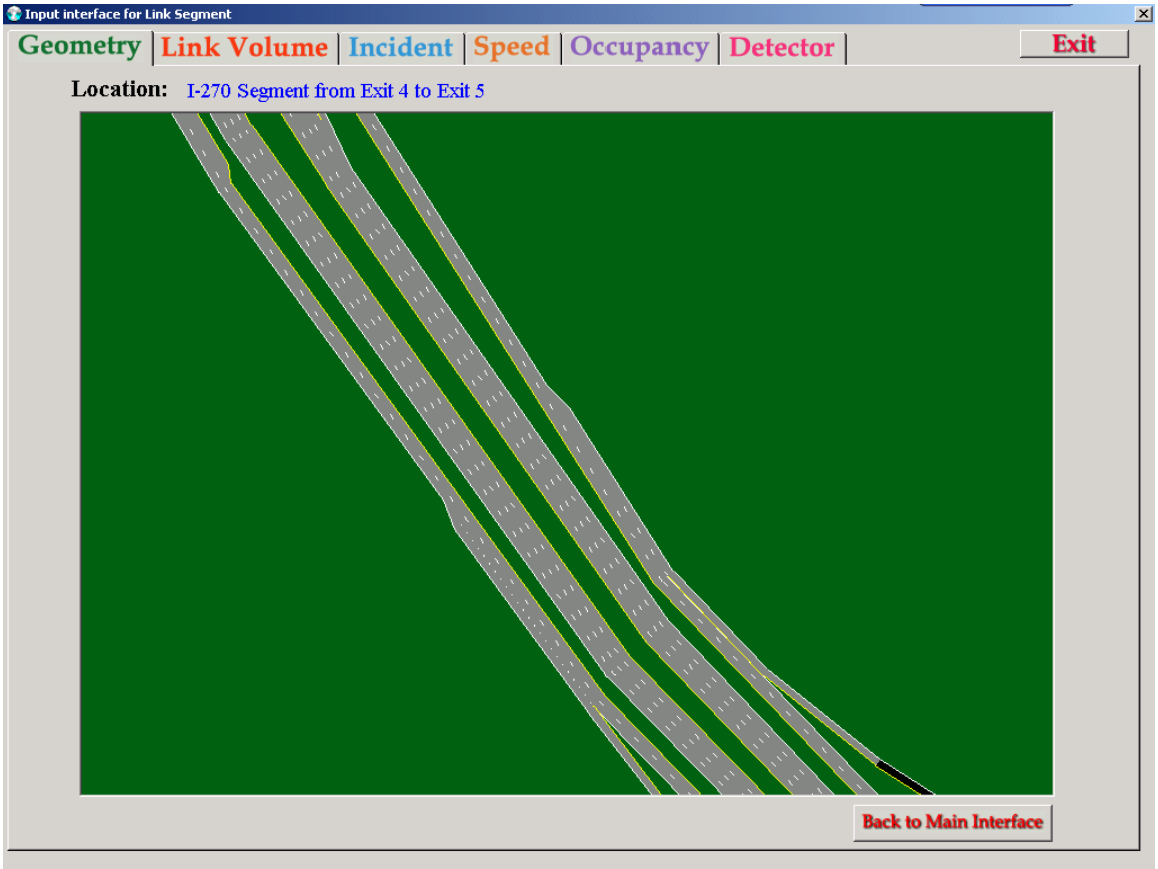


Figure 3-3: Interface for the Input of Link Segment Geometry

The interface for link input enables users to input or change any of the following information:

1. *Geometric features*-- Figure 3-3 shows the link geometric information, where one can change the number of through lanes and the length of auxiliary lane.

2. *Link Volume*-- The interface of link volume input contains two frames (see Figure 3-4), where the left one is used to input the new link volume record, and the right one lists the available archived volume data.

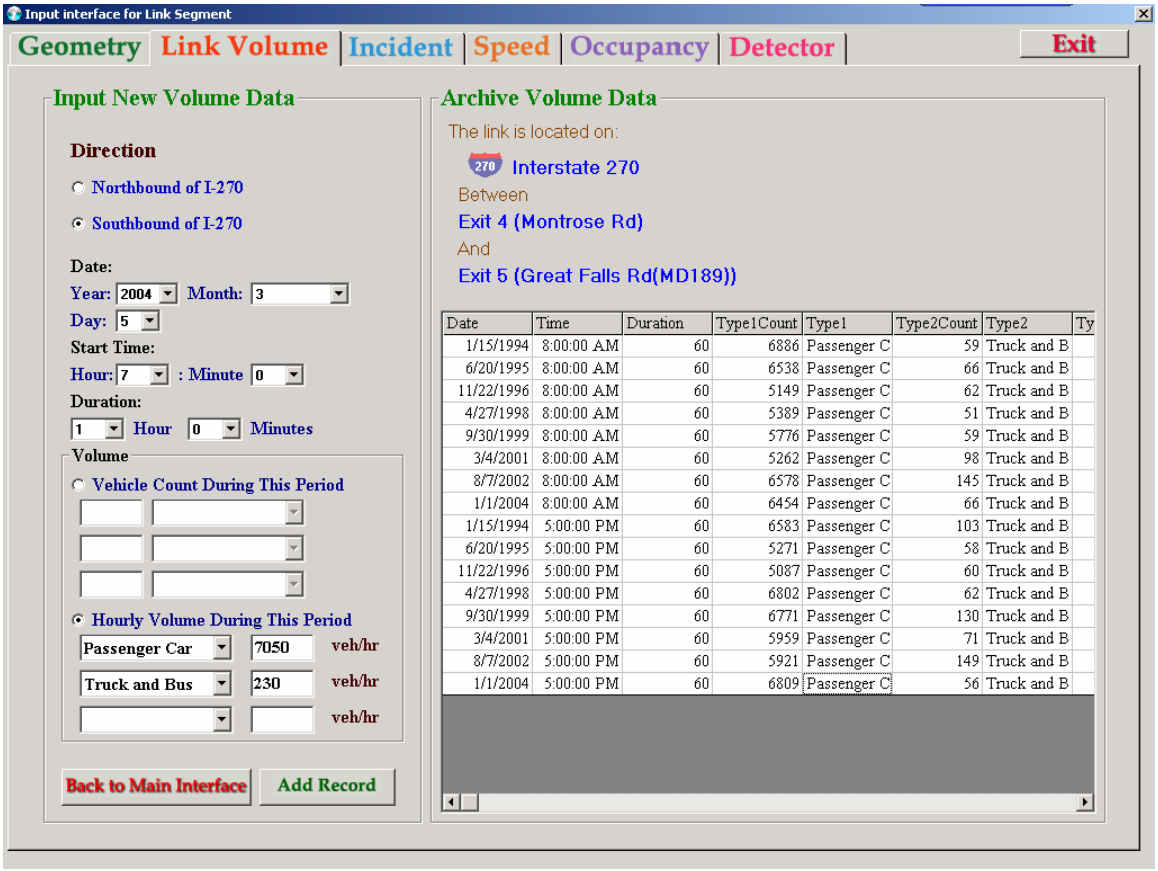


Figure 3-4: Link Volume Input

For adding new data, the following information listed in the left frame should be completed:

- *Direction:* The direction of traffic flow.
- *Date:* The date of link volume survey.
- *Starting time:* The starting time of link volume survey.
- *Duration:* The duration of link volume survey.
- *Volume:* Either the total number of vehicles during the survey period, or vehicles per hour.
- *Link location:* The road name, its upstream exit and downstream exit numbers.

3. *Incident reports*-- To input incident related information, the interface will ask the users to answer the following questions in sequence:

- Direction of the blocked lanes.
- Approximate distance from the incident location to the nearest upstream or downstream ramp.
- The exact lane blockage information (e.g. the leftmost lane, or the shoulder lane).
- Incident onset time, arrived time of response units, cleared time, and incident nature.

The series of interface frames for users to input the above information are shown in Figures 3-5 to 3-8.

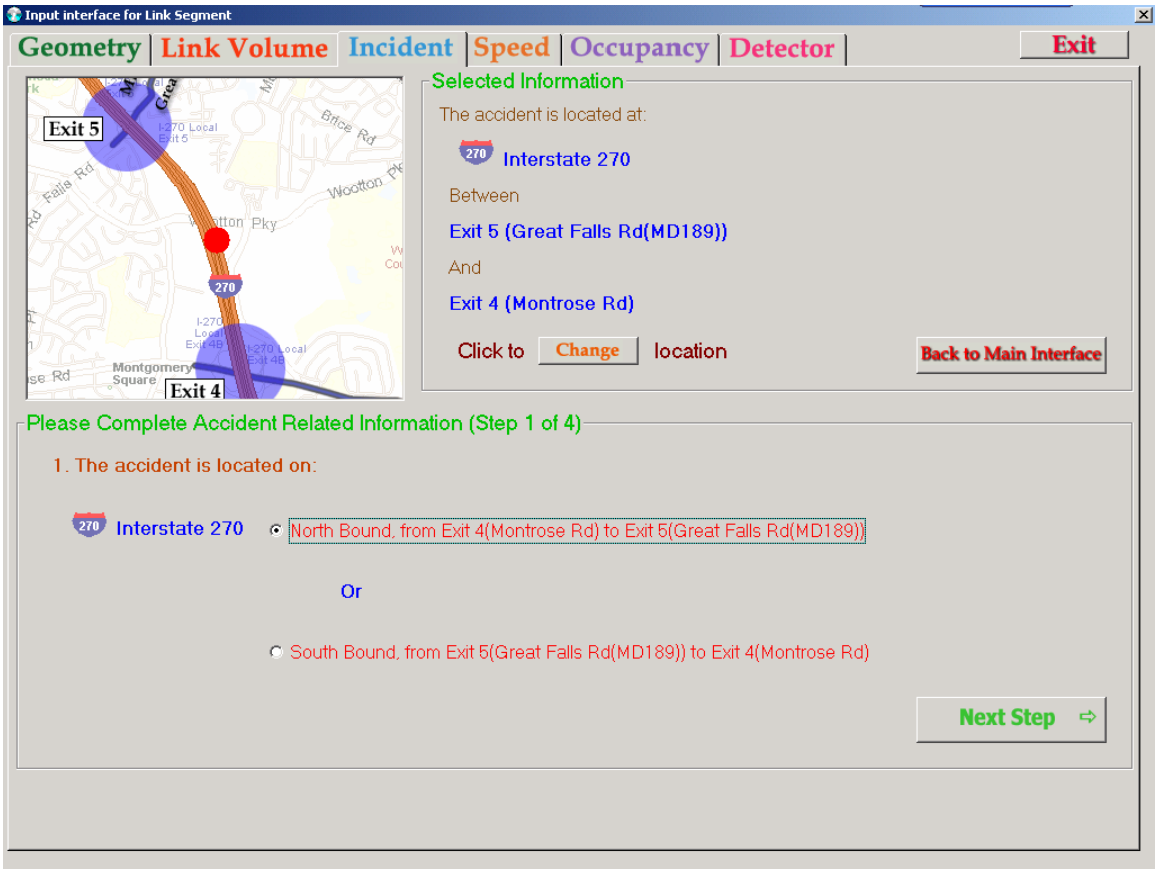


Figure 3-5: Incident Information Input (Step 1)

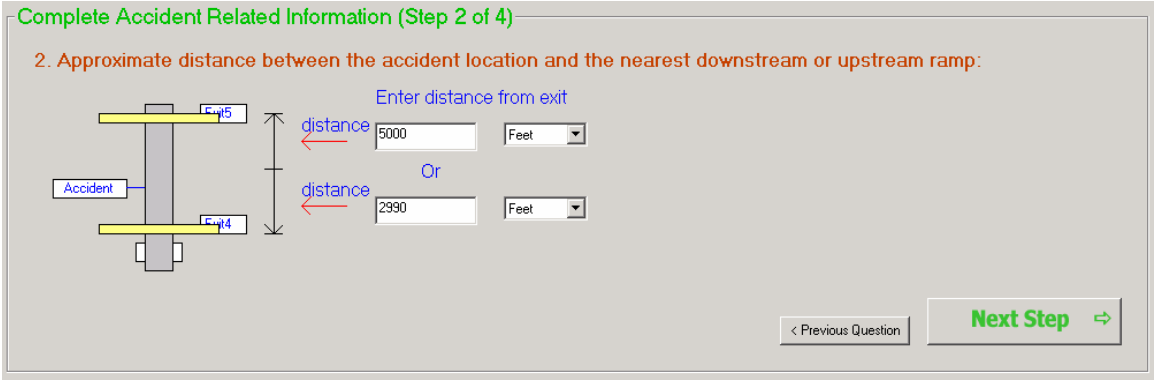


Figure 3-6: Incident Information Input (Step 2)

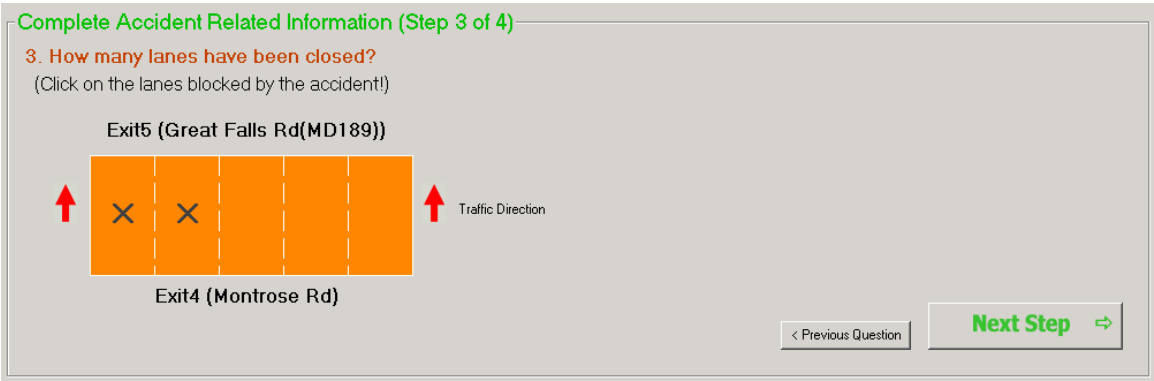


Figure 3-7: Incident Information Input (Step 3)

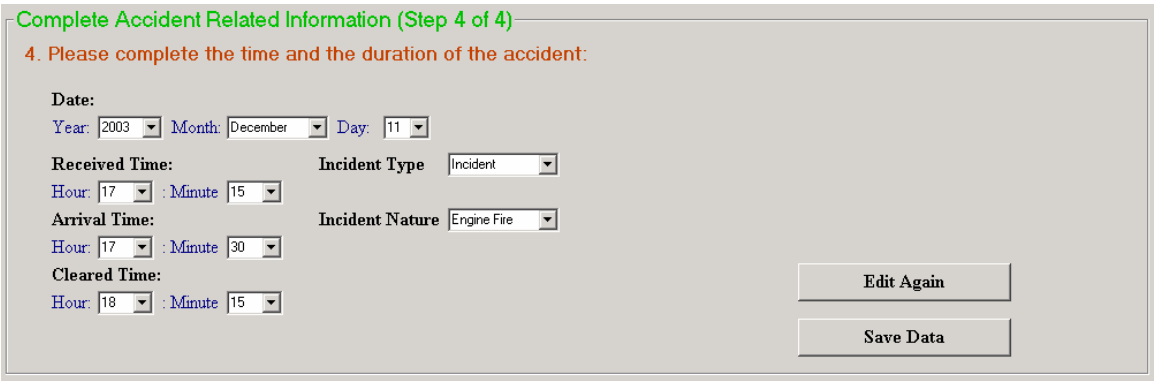


Figure 3-8: Incident Information Input (Step 4)

4. *Flow speed and occupancy data*: Both the speed and occupancy data available from on-line data can be compiled and transferred automatically to the system with an on-line integration function. However, for some speed information measured using probe

vehicles with GPS, the interface frame shown in Figure 3-9 can be used to transport the data directly to the database.

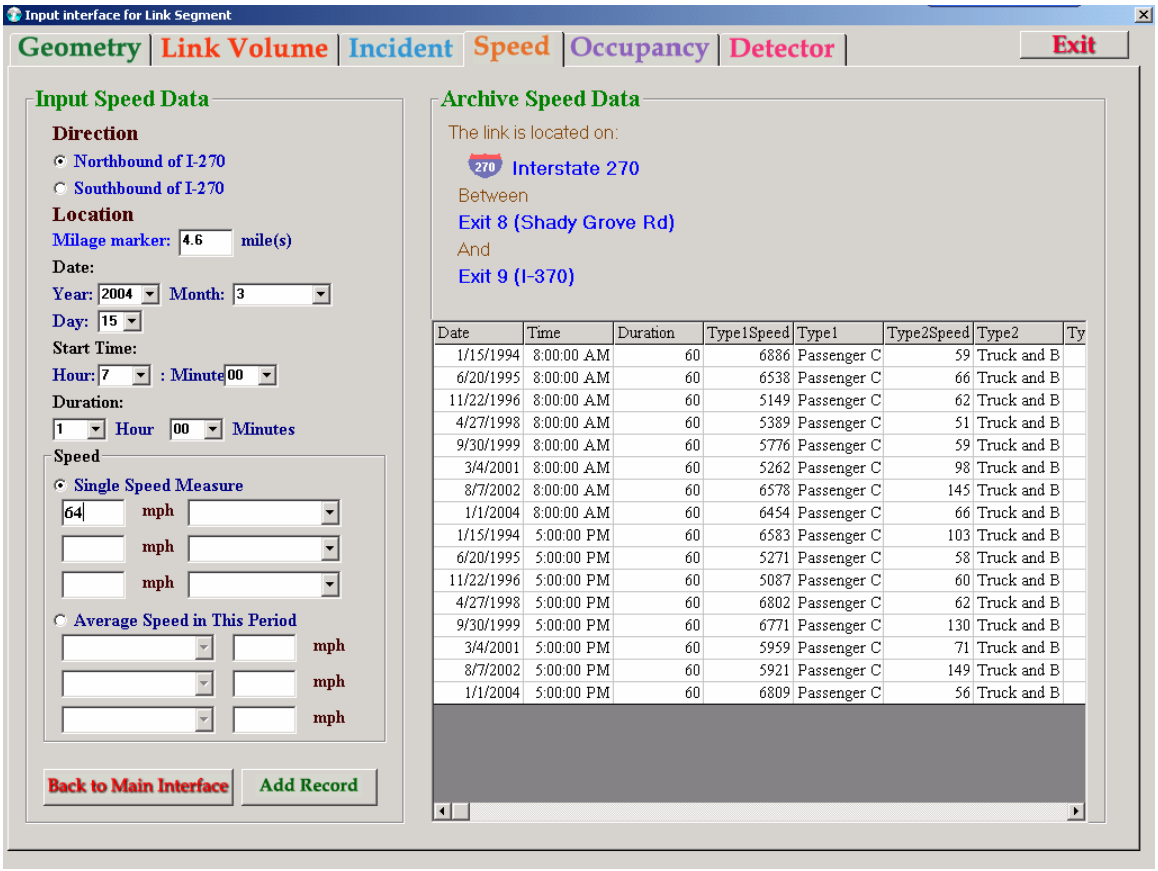


Figure 3-9: Speed Input Interface

5. *Detector function:* This is to record the availability of detectors on the target highway facility, which will allow system operators to document information associated with each deployed detector station, including its maintenance and performance quality or reliability.

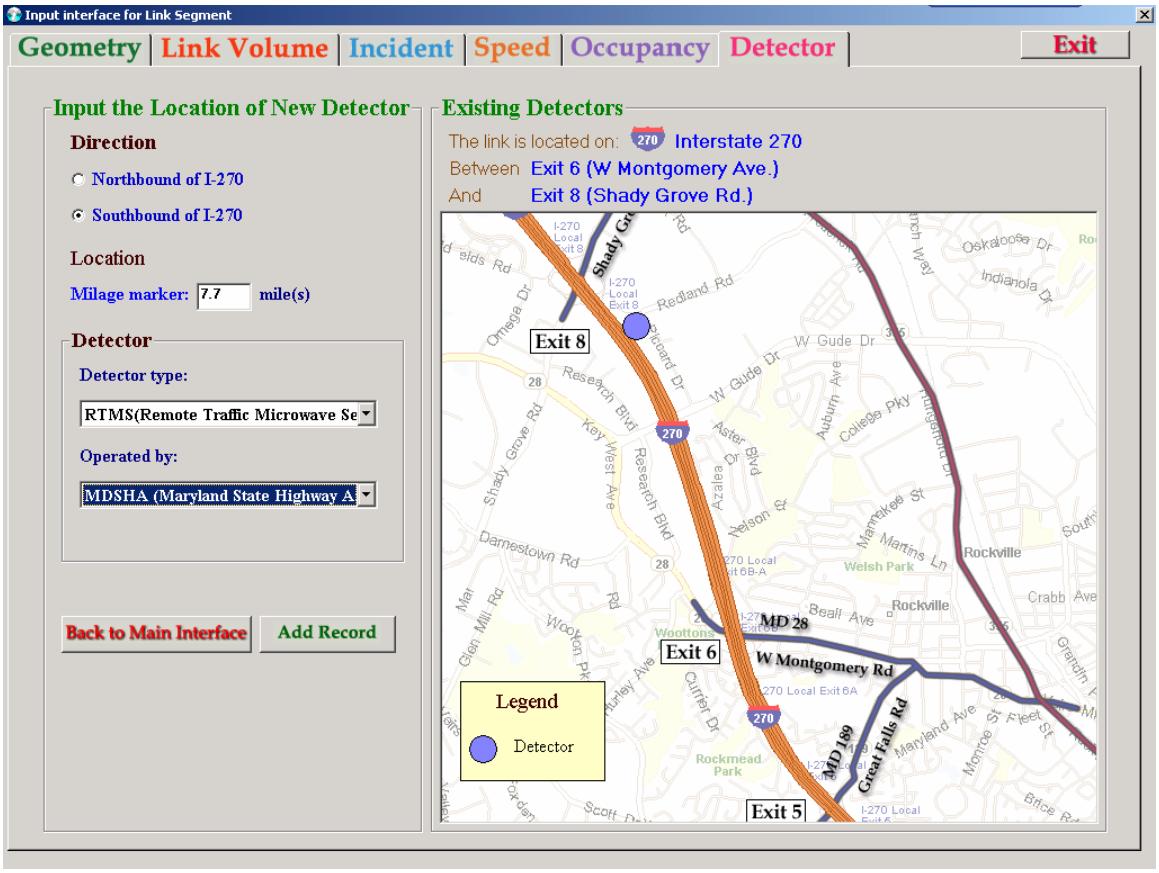


Figure 3-10: Link Detector Input Interface

3.4 Interchange Data Input

The interfaces for interchange-based information input includes the following module:

- *Geometry:* Displays the geometric features of the selected interchange.
- *Turning Fraction:* Inputs the turning fraction for all exits of the selected interchange. Users should input the time period and duration for all volume related information.
- *Travel time:* Inputs the travel time information for the mainline section between two specified interchanges. Users are required to provide date and departure time of the travel time survey, the exit number for both the origin and destination, vehicle type and travel time.
- *Detector:* Inputs the location information for on- and off- detectors.

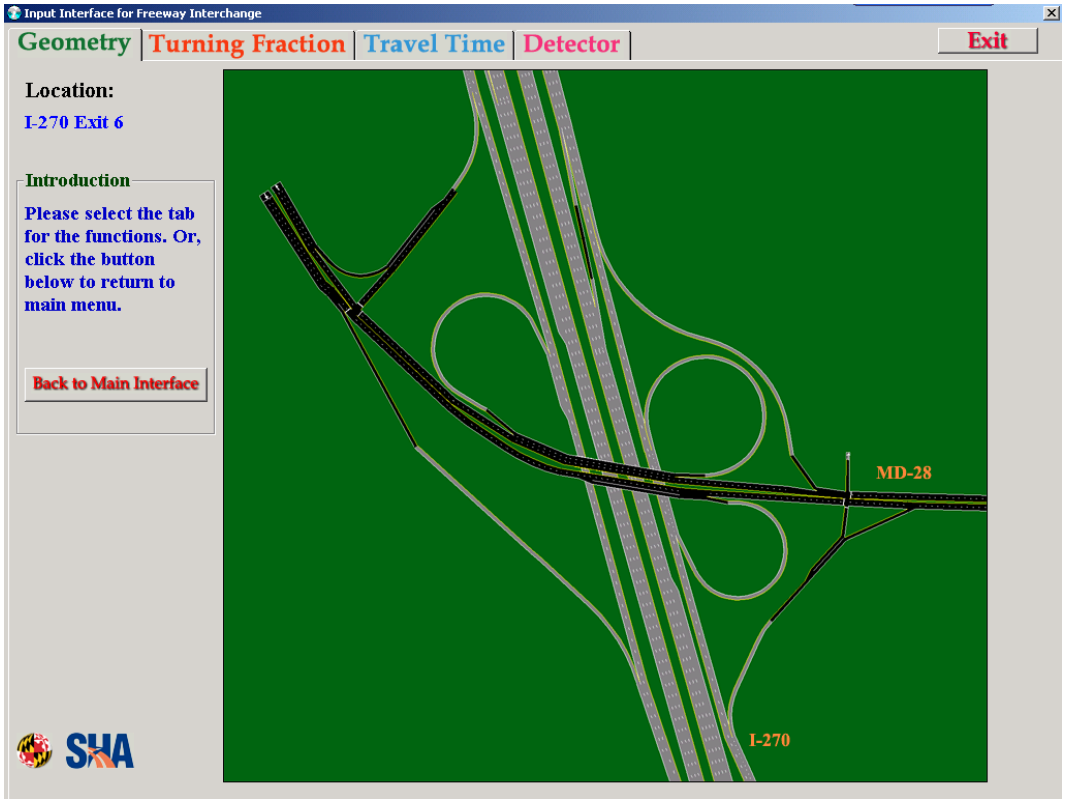


Figure 3-11: Interchange Geometry Interface

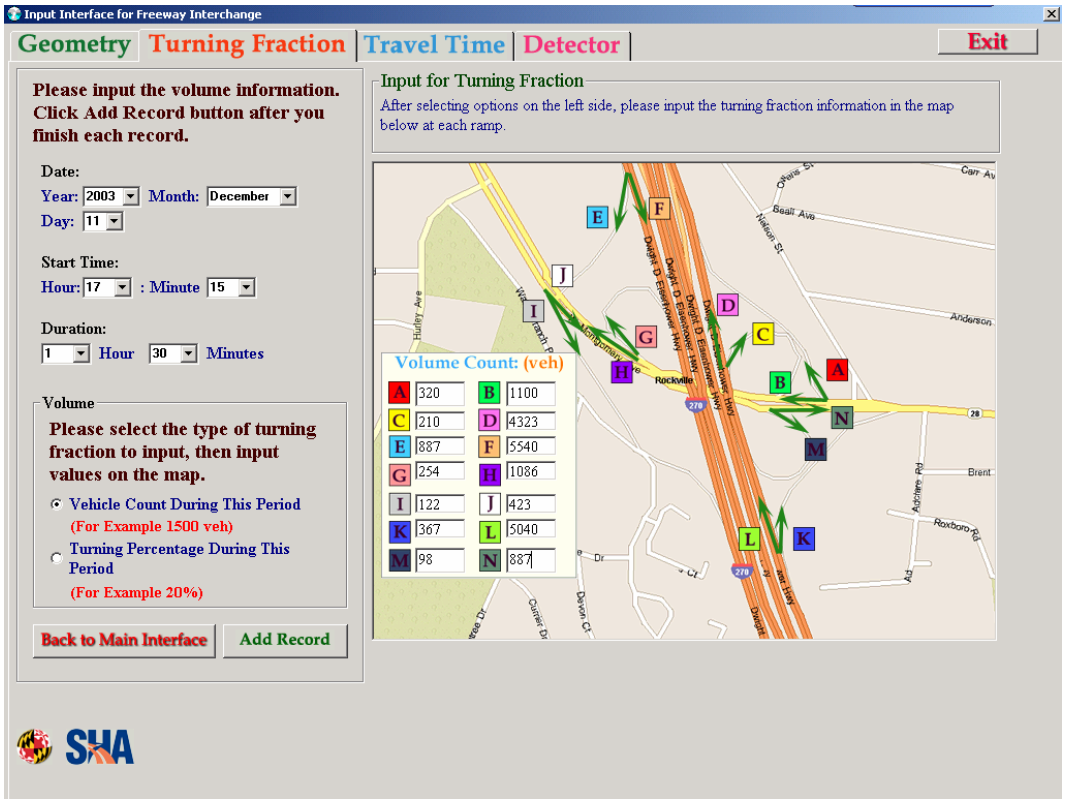


Figure 3-12: Turning Fraction Input Interface

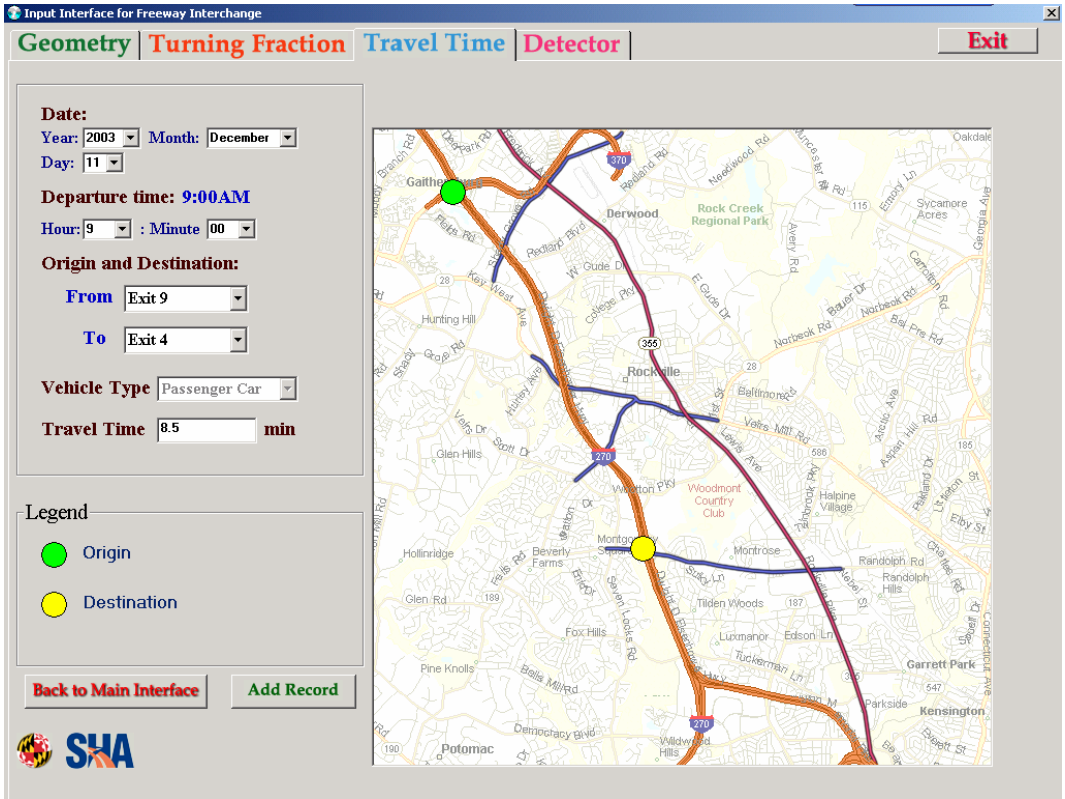


Figure 3-13: Travel Time Input Interface

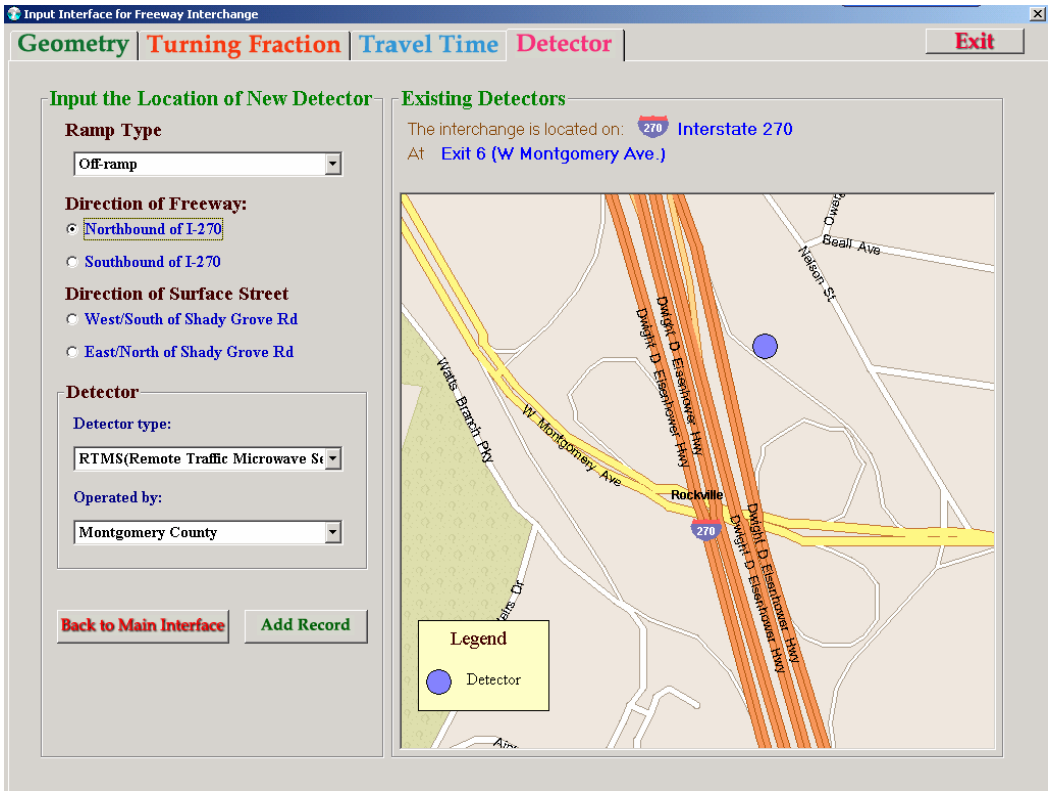


Figure 3-14: Interchange Detector Input Interface

3.5 Intersection Data Input

The interfaces for intersection-based information input includes the following module:

- *Geometry:* Displays the geometric features of the selected intersection. Users can change the lane group configuration, as shown in Figure 3-15.
- *Turning volume:* Inputs the turning volume (vehicle/hour) for all approaches of the selected intersection. For right turn volume, users can set the percentage of 'No Turn On Red', 'Free Right Turn', or 'Right Turn Overlap'.
- *Signal timing:* Change the phasing and timing setting of selected intersection.
- *Detector:* Setup the detector location and type information if the intersection uses adaptive signal controls.

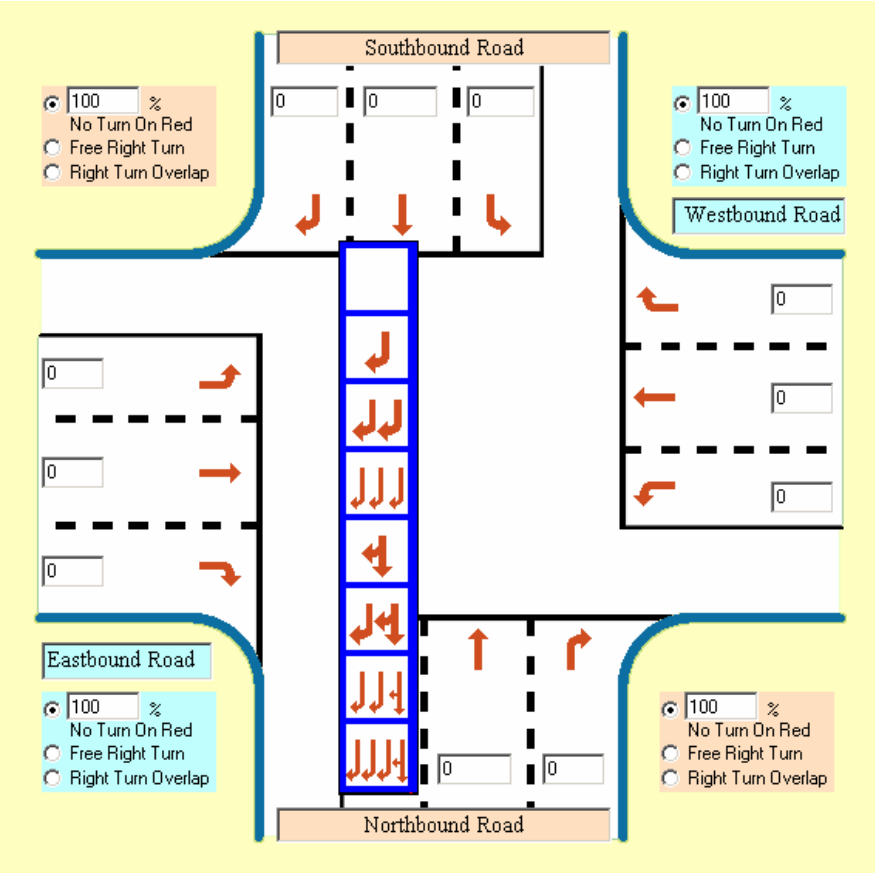


Figure 3-15: Intersection Geometry Interface

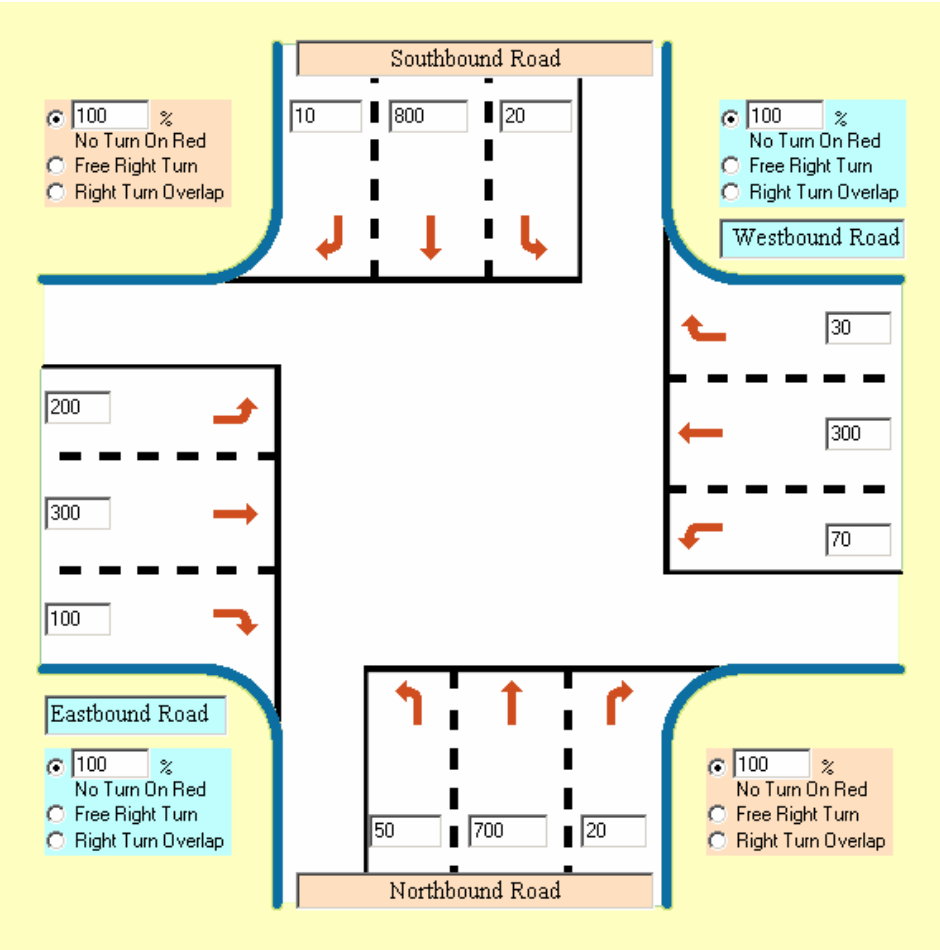


Figure 3-16: Intersection Volume Input Interface

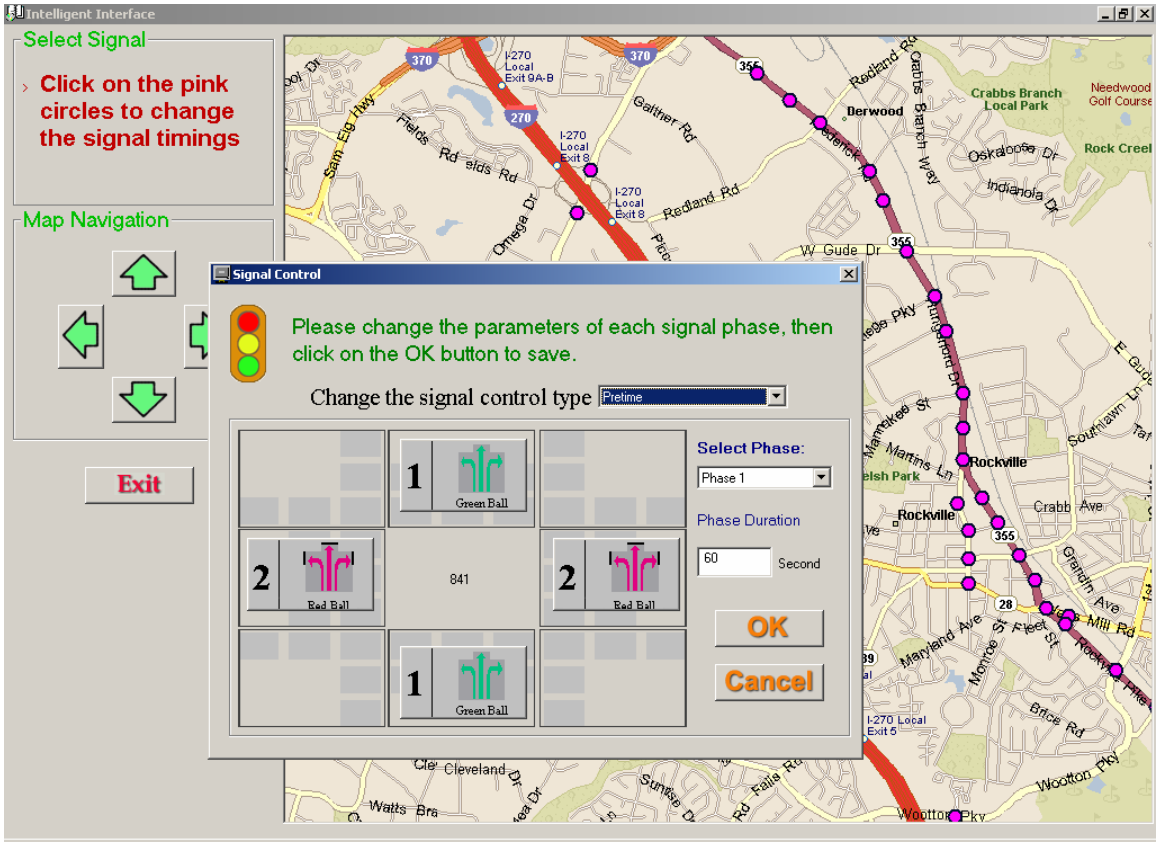


Figure 3-17: Intersection Signal Control Interface-1

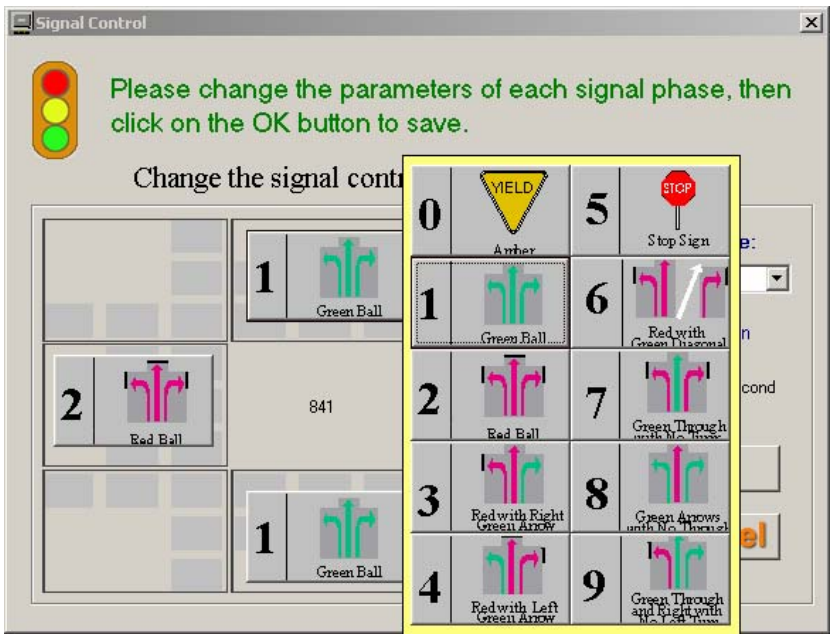


Figure 3-18: Intersection Signal Control Interface-2

Chapter 4
Description of the Information Query Module

4.1 The Information Query Module

This chapter describes various components of the Information Query Module (IQM), such as data availability, data query functions, and multiple output methods. The main purpose of the IQM is to assist users in taking full advantage of all available information from the Integrated Traffic Information System (ITIS), and to support a variety of traffic planning or operations related work. Examples of applications include:

- Preparation of traffic condition reports for a target highway segment (e.g., speed, delay, volume, and geometric features).
- Analysis of traffic safety improvements (e.g., incident frequency, distribution, nature).
- Planning and comparison of work zone operational plans.
- On-line and off-line estimation of traffic conditions for both recurrent and non-recurrent congestion.
- Evaluation of incident response operations.

In order to facilitate the aforementioned applications, the proposed IQM integrates the advantages of query and map-based methods into a user-friendly interface that enables users to search the following categories of information (see Figure 4-1):

- Traffic volumes
- Signal phase and timing plans
- Travel times
- Incidents and related data
- Speed measurements
- Occupancy or density
- Detector information
- Operational References and Guidelines (i.e. work zone operations)

Figure 4-1: Data Search Interface

4.2 Data Availability Query Function

This function is designed for users to check the data availability associated with the target area and applications. To do so, the users need to select a target category from the following list:

- Link volume
- Turning fraction
- Speed
- Occupancy
- Travel time
- Geometry
- Signal

By setting the search criteria, the system will show the availability of data from the selected data category in the map view. For example, the green legend shows that the requested data is available, while the red legend indicates that the requested data is not available. Figure 4-2 shows the data availability for link volume, and Figure 4-3 presents the speed data availability.

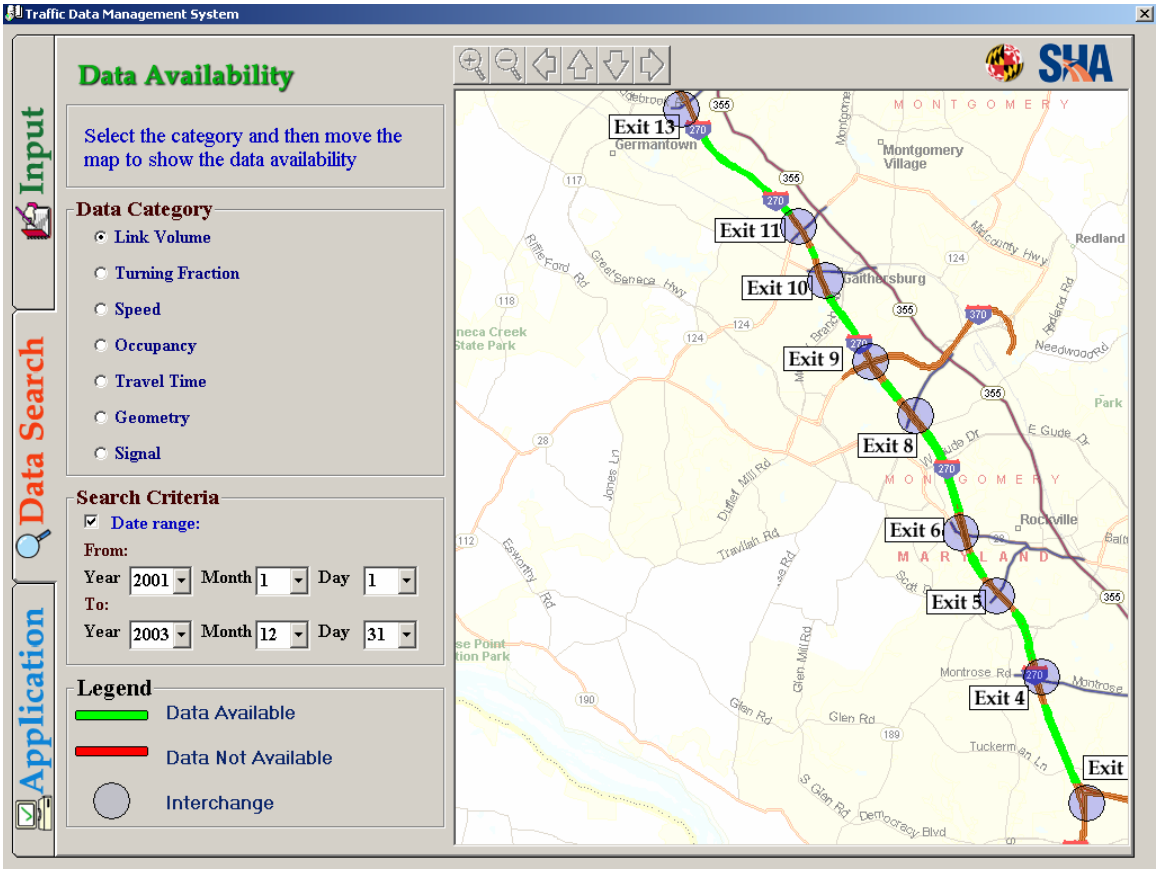


Figure 4-2: Availability of Link Volume Data

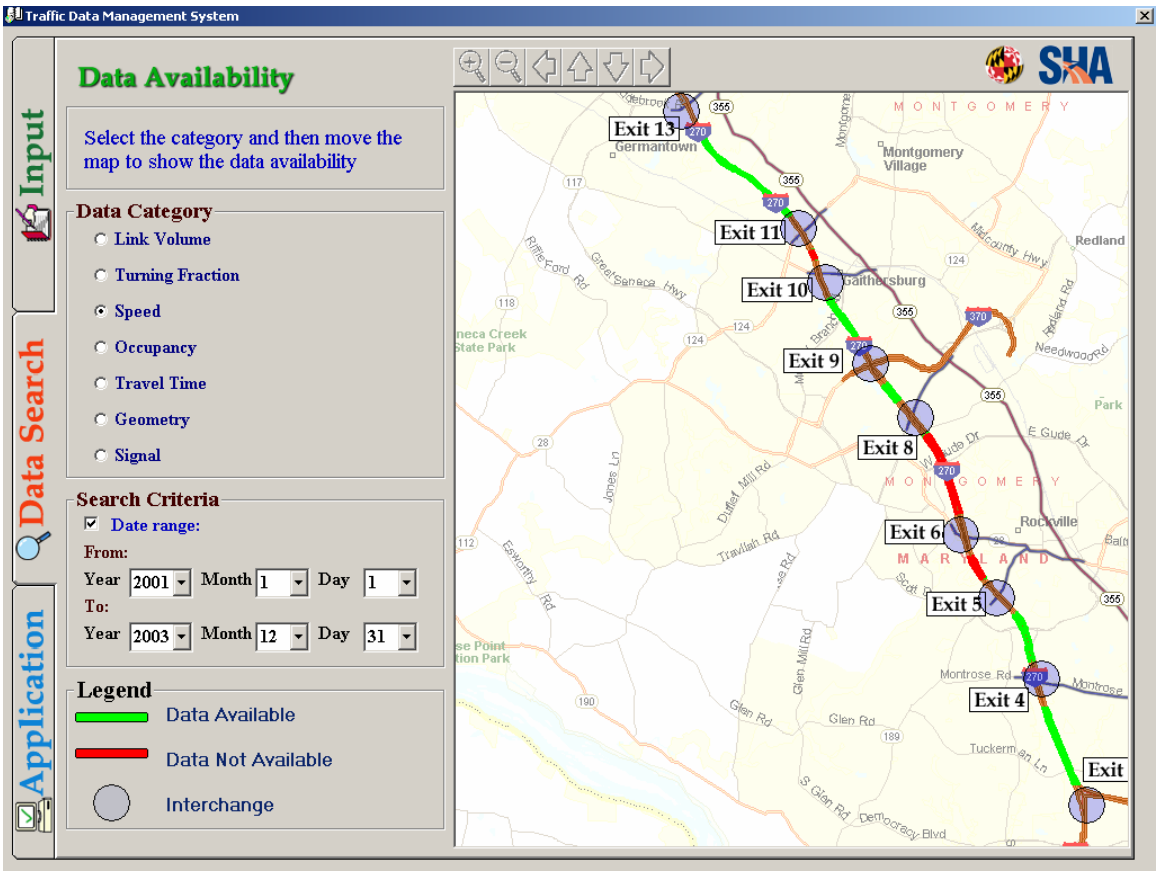


Figure 4-3: Availability of Speed Data

4.3 Volume Data Query Functions

In order to query volume related data, the first step is to select a freeway segment, and identify its available data, as illustrated in Figure 4-4.

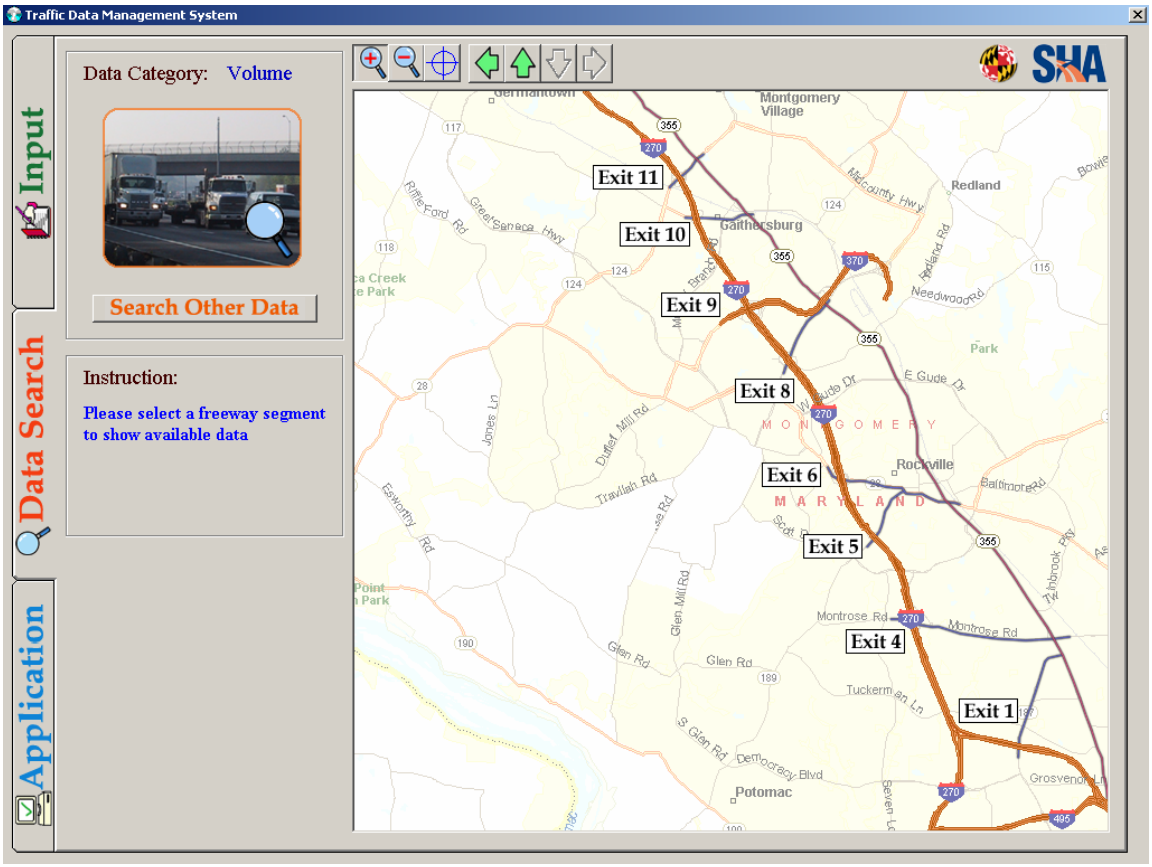


Figure 4-4: Volume Data Query (Step 1)

Secondly, the user should set the search criteria by inputting the traffic direction and the range of date and time periods. The search results of volume data will appear automatically in the displayed tables.

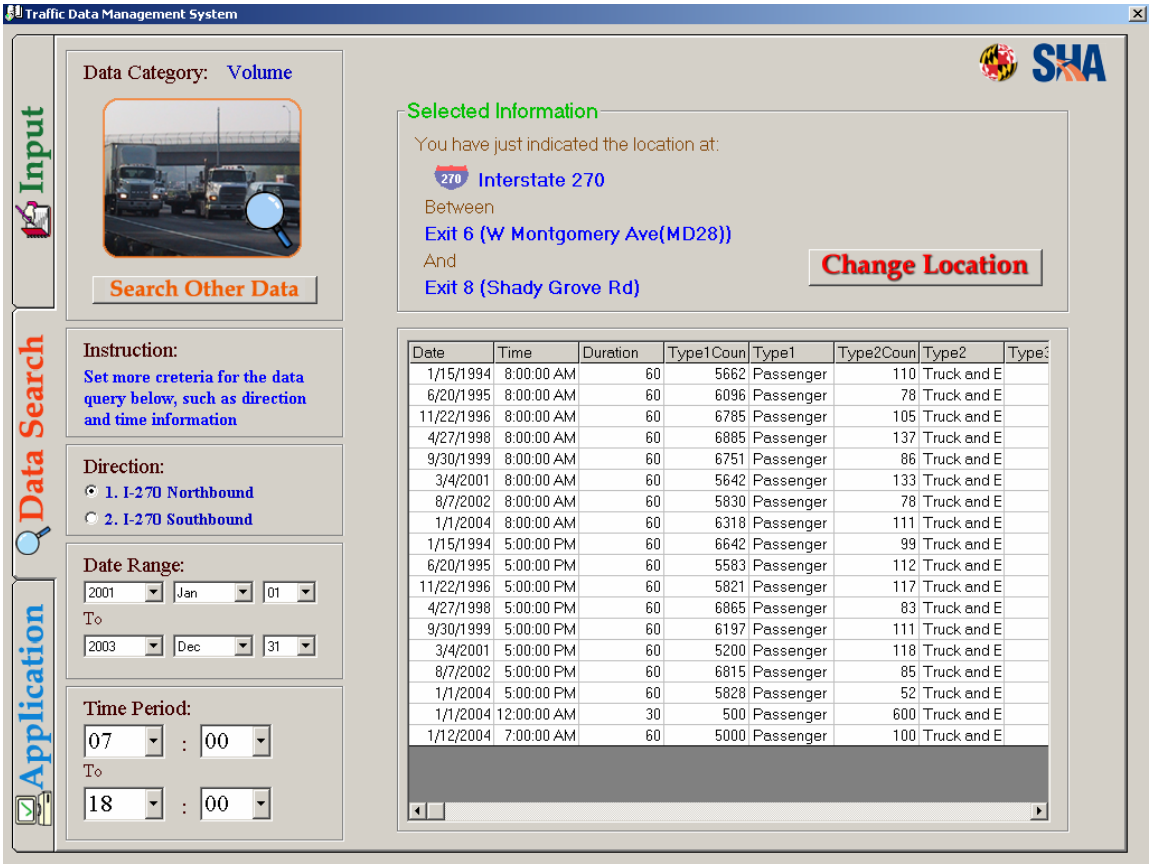


Figure 4-5: Volume Data Query (Step 2)

After querying the available volume data for the specified range of date and time periods, the system will use this information to estimate any missing volume data. Figure 4-6 shows the estimated missing volume data. The example, shown in Figure 4-6, employs the archived volume data over the past 10 weeks, which are from 5 a.m. to 11 a.m. on Wednesday. This data will be used to estimate the missing volume for 7 a.m. – 8 a.m. on Nov. 19, 2003. A detailed description of the estimation methodology is available in Chapter 5.

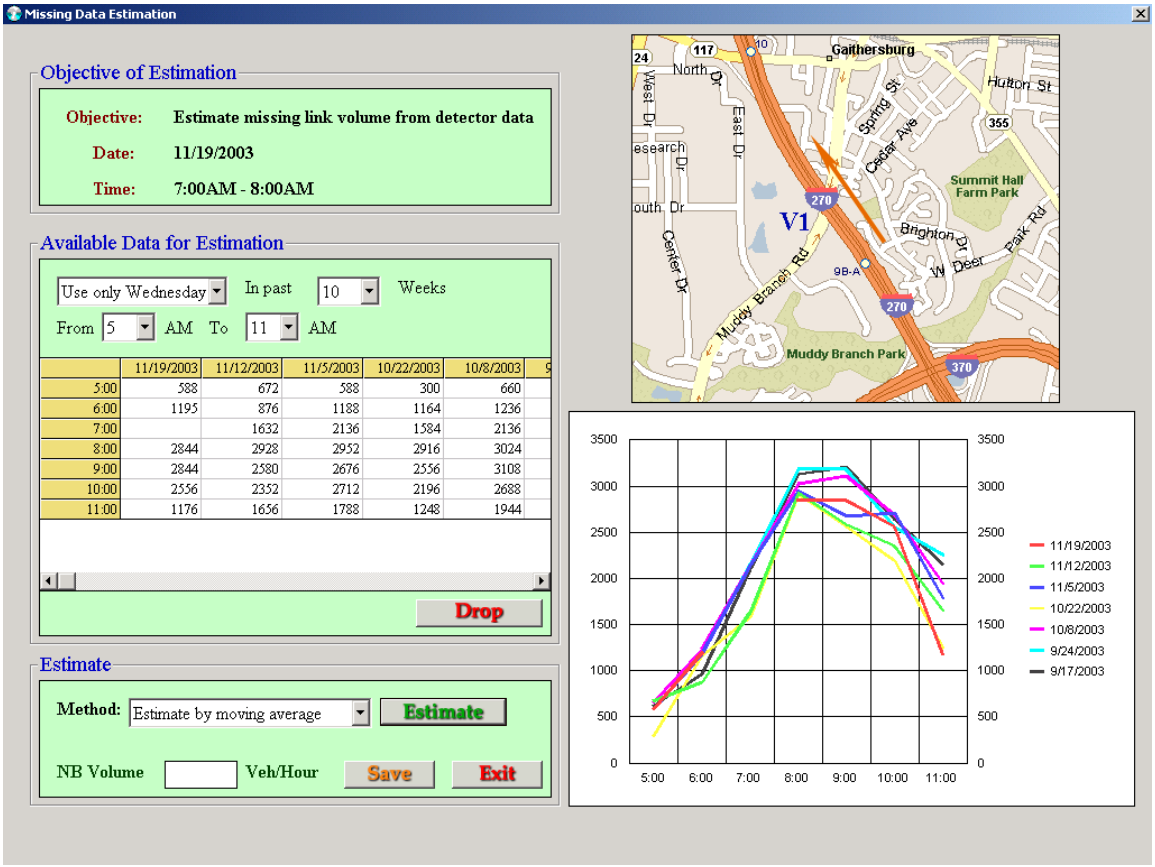


Figure 4-6: Volume Data Query Used for Missing Data Estimate

4.4 Incident Information Query Function

By using these query functions, users can obtain all incident related data and response performance information available in the CHART evaluation database.

The following information associated with each primary highway segments are imported directly from the CHART performance database:

- Number of incidents
- Average incident duration
- Average lane blockage
- Average response time
- Average clearance time

– Spatial distribution of different types of incidents.

Figure 4-7: Select the Type of Incident Information

Depending on the purpose of application, potential users should specify the type of incident related information from the following list:

– Peak hours and off peak hours

– Week day and weekend

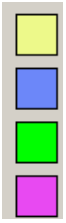
– By lane blockage

– By incident nature

After specifying the required information and pressing the search button, the system will generate a set of map-based incident information queries, as shown in Figure 4-7.

Figure 4-8: Select Types of Data Series

In the incident information query output interface, users can redefine the type of incidents, and the range of data to be searched from the database. The output map will automatically respond to each requested change. Data charts are displayed at the center of each associated link segment, where different legends represent different data series. Figure 4-9 illustrates the use of four legends representing the following four types of lane blockage:



One-lane blockage

Two-lane blockage

Three-lane blockage

Four-lane blockage or

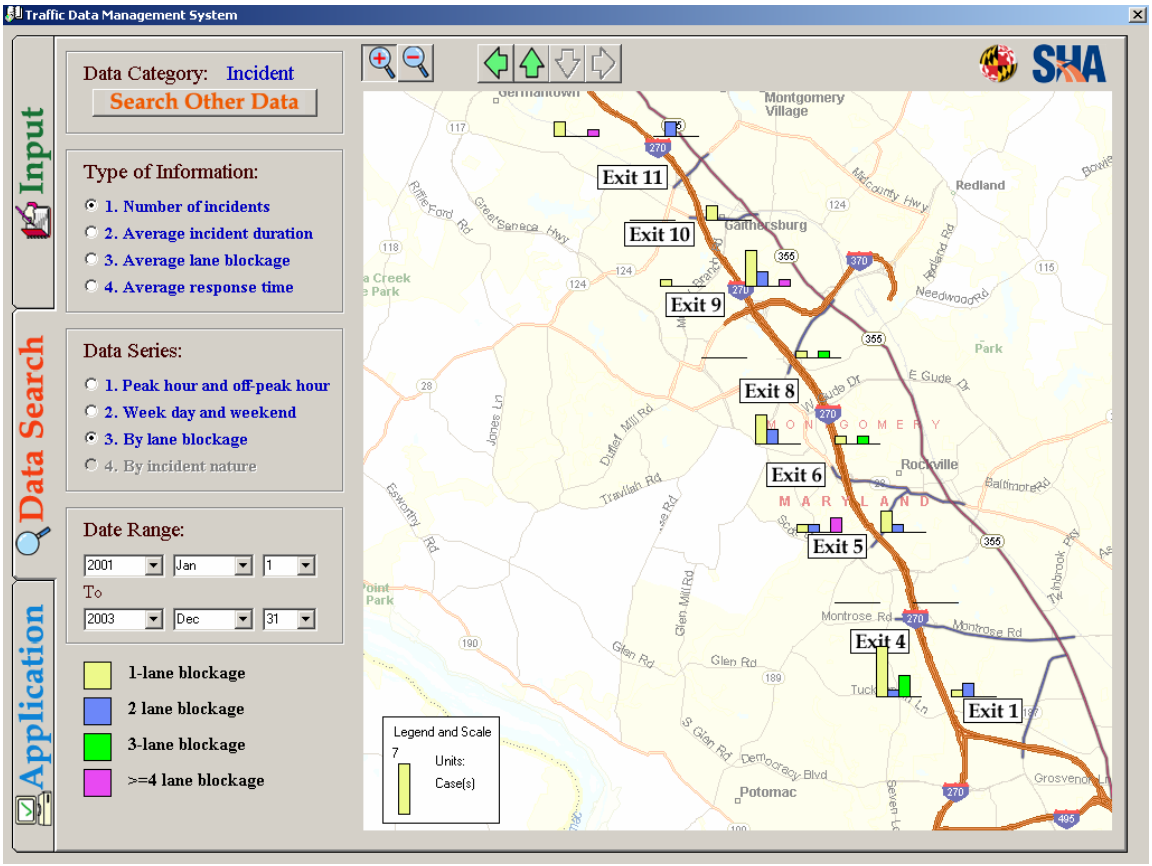


Figure 4-9: Output of Incident Information Query

Users can select the view of the incident information by using other types of data series. Figure 4-10 illustrates the distribution of average incident duration time along I-270 for weekdays and weekends. Figure 4-11 highlights the distribution of average response times on I-270 during peak and off-peak hours.

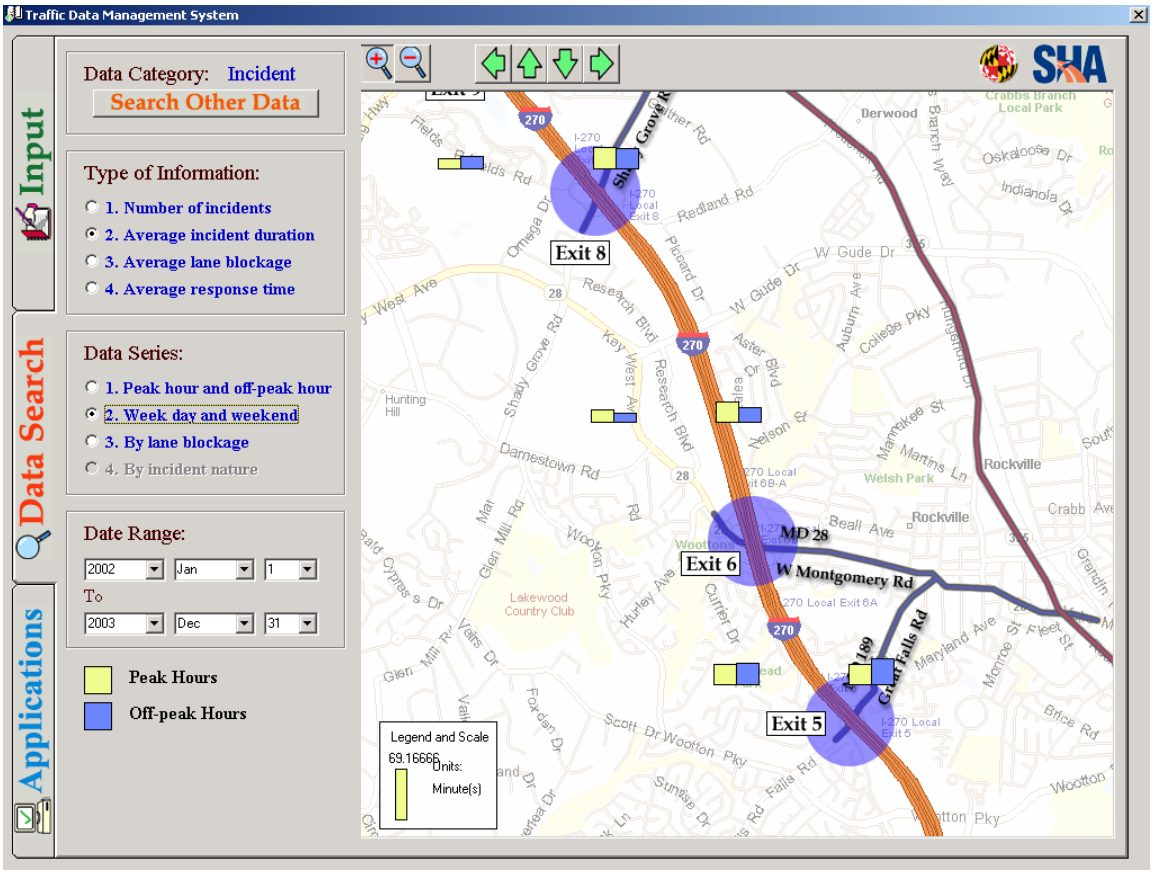


Figure 4-10: Distribution of Average Incident Duration for Weekday/Weekend

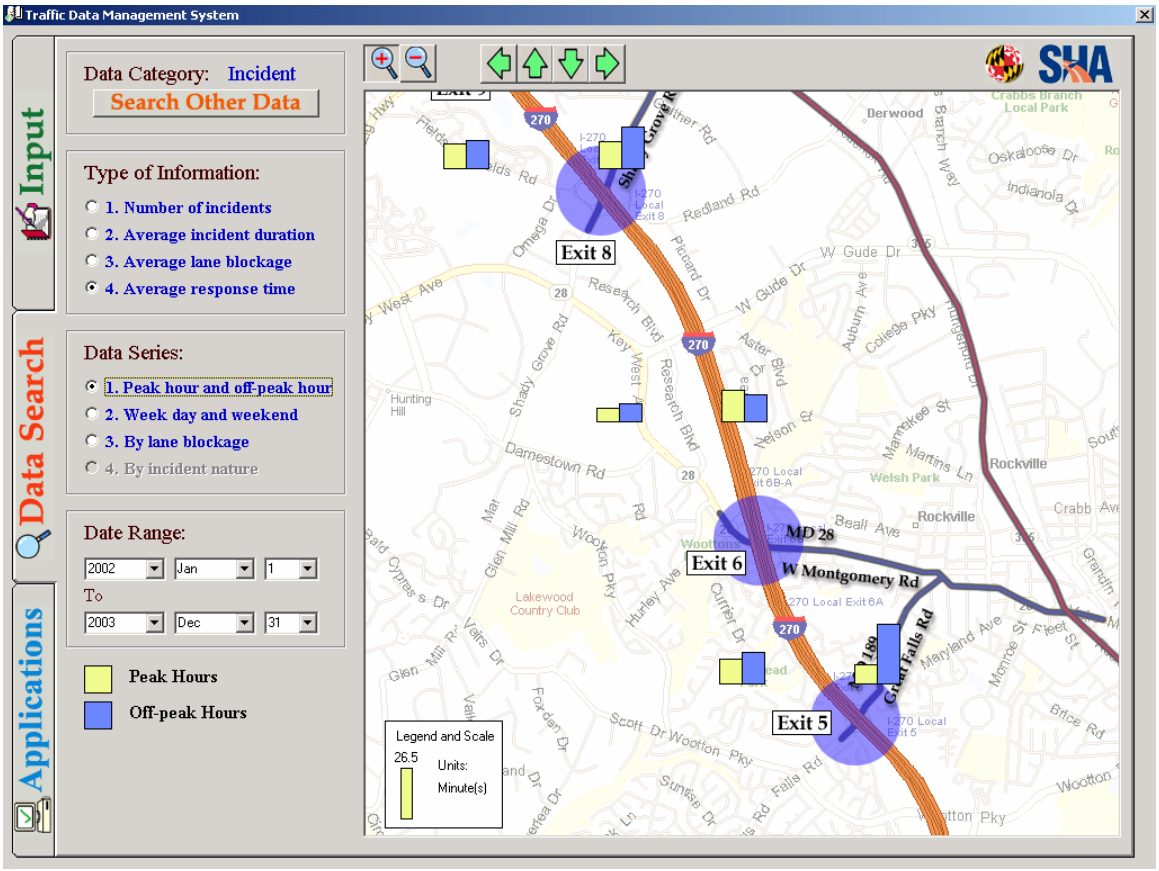


Figure 4-11: Distribution of Average Response Time for Peak/Off-Peak Hours

Figure 4-12 shows the distribution of incidents and disabled vehicles by location on I-270 in 2002. Figure 4-13 shows the frequency of incidents by nature in Maryland in 2002.

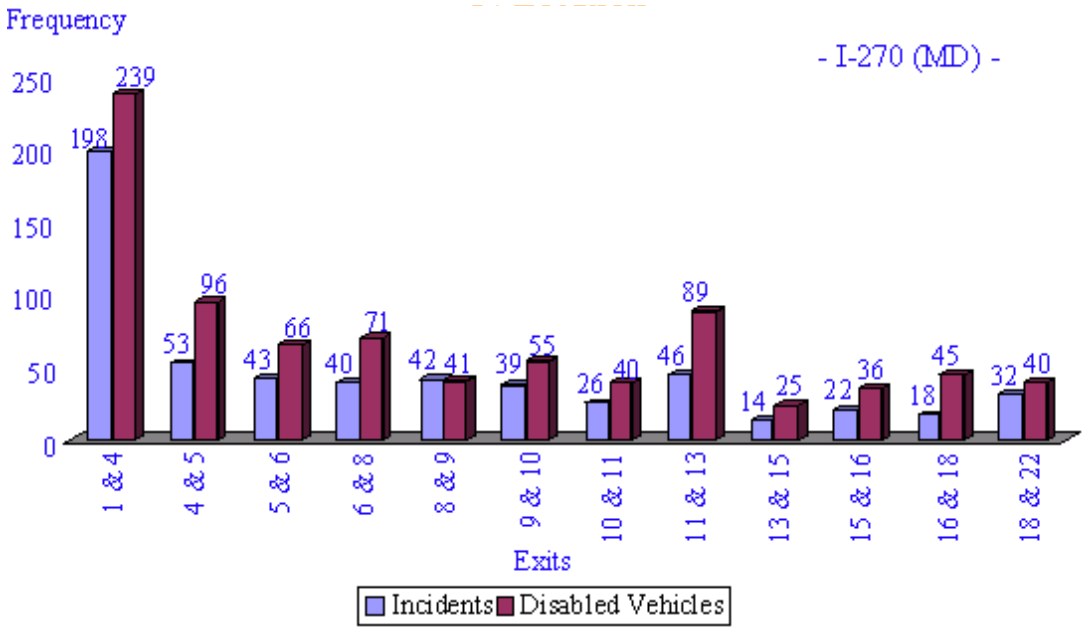


Figure 4-12: Distribution of Incidents and Disabled Vehicles

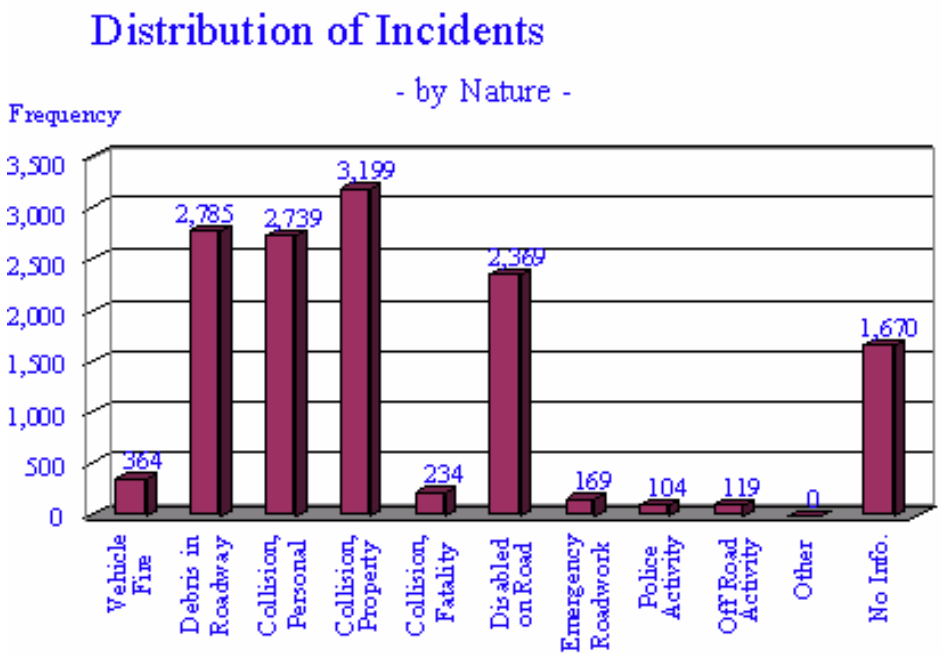


Figure 4-13: Distribution of Incidents by Nature

4.5 Conclusion

This chapter presented the key functions of the Information Query Module (IQM), which is designed to assist potential users in taking full advantage of available information provided by the Integrated Traffic Information System (ITIS). Through a carefully designed interface, users without any computer operation knowledge can easily use the proposed ITIS for either preliminary traffic analysis or advanced on-line incident management as well as impact estimation.

Chapter 5
Methodology for Estimating Missing Volume Data

5.1 The Need to Estimate Missing Volumes

In the proposed Integrated Traffic Information and Simulation (ITIS) system, traffic volume data is essential information used in performing simulation analyses. However, due to high implementation costs, most state highway networks do not have adequate coverage of surveillance sensors, which are needed in order to provide sufficient traffic volume data for either off-line or on-line simulation applications. Thus, without complete surveillance sensor coverage, traffic engineers cannot effectively estimate traffic volume for locations without detectors.

This chapter presents two algorithms for estimating missing data, using available detector or archived information. The first algorithm is designed for a scenario where the available data for use in missing volume estimations has the same level of quality as that from on-line detectors or archived information. The second algorithm is developed for use in a generalized scenario that consists of both on-line and archived information used in performing the estimation. For example, a freeway corridor may have detectors or counter stations on its mainline segment, but not at its ramps. Thus, the estimation of real-time ramp volumes would rely on on-line detector data of the mainline segments and any available historical ramp volumes. These two types of information certainly have different levels of quality, and the estimation algorithm will address such differences.

Due to the mathematical complexity of these two algorithms, the remaining sections will use numerical examples to further explain the illustrations. The interface in the ITIS used for projecting the missing data estimation is presented in the last section. All numerical examples presented in the remaining sections are generated from the I-95 freeway corridor rather than from the I-270/MD 355 corridor. This is due to the fact that the I-95 has relatively complete mainline and ramp volumes for generating a realistic example, and the detector stations in the I-270/MD 355 corridor at this stage provide only speed information.

5.2 Algorithm-1: Available Data has the Same Quality

This section uses the freeway segment of I-95 northbound between I-495 and I-695 for generating illustrative examples and for presenting the estimation methodology as well as procedures (see Figure 5-1).

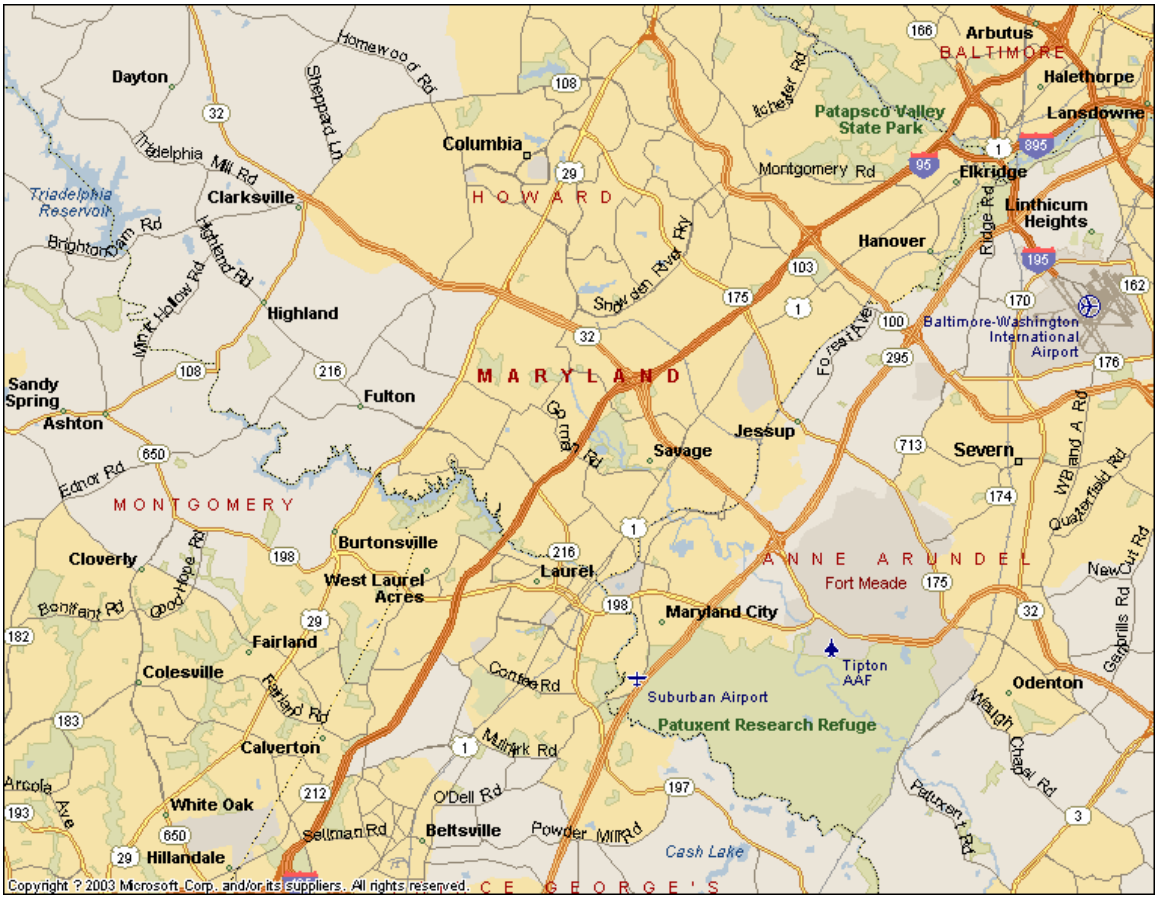


Figure 5-1: A Graphical Illustration of the Freeway Segment Discussed in the Numerical Examples

The design used in the illustrative examples consists of the following principal steps:

Step-1: Use the available historical ramp volumes on the target I-95 corridor to execute the I-95 simulator.

Step-2: Compute the volume of each mainline link based on the simulation results, and use this set of mainline volumes as the base-line volume set (called base-main volume).

Step-3: Perform a random variation of volume on the base-main volume set,

and generate a new set of mainline volumes (called updated-main volume).

Step-4: Execute the proposed methodology to estimate the new set of ramp volumes (called new-ramp volume) under the new set of mainline volumes.

Step-3 replicates the scenario in which mainline volumes may have been updated from some available source (e.g., detectors) , which means that ramp volumes should also be re-estimated. Additionally, in order to evaluate the quality of data from the proposed estimation methodology, the differences between the mainline volumes generated from the simulation with the new-ramp volume and those in the updated-main volume set can be compared. The rationale is that the ramp volumes from Step-4 should be able to yield the same set of mainline volumes as generated from Step-3 if they are correctly estimated. The mathematical expression of the core logic for missing volume estimation is presented below:

Model formulations

- *Available information:*
  - Original set of historical mainline volumes;
  - Original set of historical on/off ramp volumes;
  - Newly updated set of mainline volumes (i.e. from some reliable sources, such as detectors).
- *Missing information to be estimated:*
  - Updated volume for each on or off-ramp

- *Objective function:*

$$\min Z = \frac{1}{2}\sum_{i=1}^{9}\sum_{r\in R(i)}\{[\frac{v_i^r(k)}{v_i^r(k-t)} - \frac{v_{i-1}^{main}(k)}{v_{i-1}^{main}(k-t)}]^2 + [\frac{v_i^r(k)}{v_i^r(k-t)} - \frac{v_i^{main}(k)}{v_i^{main}(k-t)}]^2\}$$

$$s.t. \qquad v_{i-1}^{main}(k) + \sum_{r\in R(i)} v_i^r(k) = v_i^{main}(k), \qquad \forall i = 1,\ldots,9 \tag{5-1}$$

Where:

$R(i)$: is the set of ramps at intersection i;

$v_i^r(k)$: is the volume at on-ramp r of intersection i at time k;

$v_{i-1}^{main}(k)$: is the volume on mainline line segment $i-1$ at time k;

$v_i^{main}(k)$:is the volume on mainline line segment i at time k;

t : is the time period when the historical volumes were collected.

The above formulation assumes that the interrelationships between mainline and ramp flows remain unchanged under the updated traffic flow patterns. Two case studies based on the above procedures for generating illustrative examples and estimation algorithms are presented below:

Case 1: Estimating the updated ramp volumes with a complete set of new mainline volumes

Figure 5-2 represents an example network for Case 1, where detector stations for volume updates are available in all 10 main links, but not at ramps. However, a set of historical volumes for all on and off-ramps are available. By applying the four principal steps presented in Equation 5-1, one can have a new set of updated ramp volumes and the resulting mainline volumes.

Table 5-1 summarizes the comparison results between the set of new mainline volumes from Step-3 and the set of mainline volumes generated with the set of updated ramp volumes from the Step-4 estimation, where:

- *Actual volume* refers to the set of updated mainline volumes from detectors or other sources.
- *Detected volume* denotes the mainline volumes generated from the simulation based on the updated set of ramp volumes estimated with Algorithm-1.
- *Difference* is defined as:

$$\textbf{Difference} = \frac{|\text{Detected Volume} - \text{Actual Volume}|}{\text{Actual Volume}}$$

It is noticeable that with a complete set of mainline volumes, the proposed algorithm can achieve quality estimations, as evident in the small percentage of estimation errors (see Table 5-1).

Table 5-1: Comparison between the estimated and actual mainline volumes in Case 1 with Algorithm-1

Location	Actual Volume	Detected Volume	Difference
1	3939	3881	1.47%
2	5120	5105	0.29%
3	4693	4674	0.40%
4	4967	4919	0.97%
5	4795	4777	0.38%
6	4699	4623	1.62%
7	5527	5483	0.80%
8	5578	5462	2.08%
9	5071	4931	2.76%
10	5136	5115	0.41%

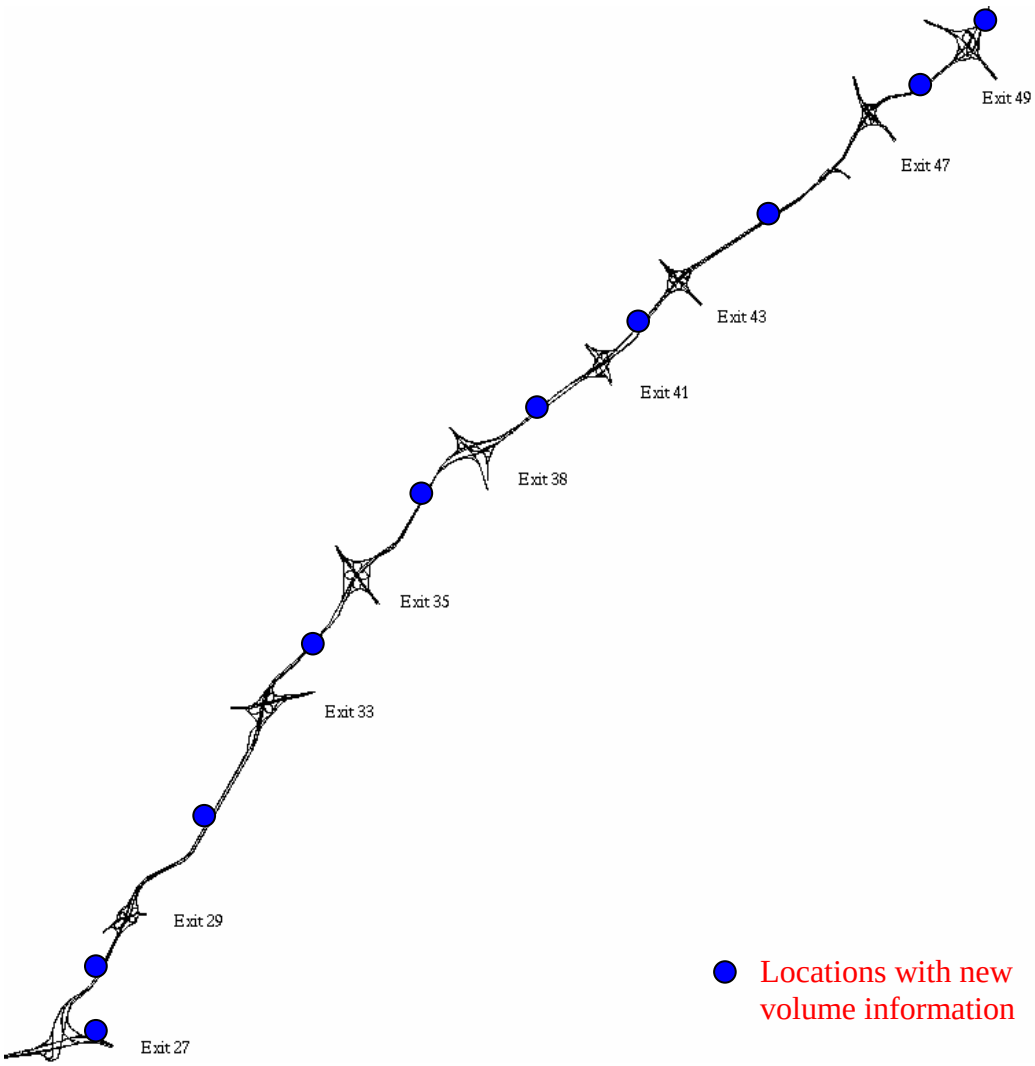


Figure 5-2: An Example Network and Available Data for Case Study 1

Case study 2: Update ramp volumes with only a partial set of mainline volumes

The same estimation algorithm can also be applied to the scenario in which some mainline segments may not have any detectors. Figure 5-3 presents the available information for Case 2, where both ramps and some mainline segments (i.e., links 2, 3, 7 and 8) have only historical volumes, and need to be updated with most recent volumes available in neighboring mainline segments.

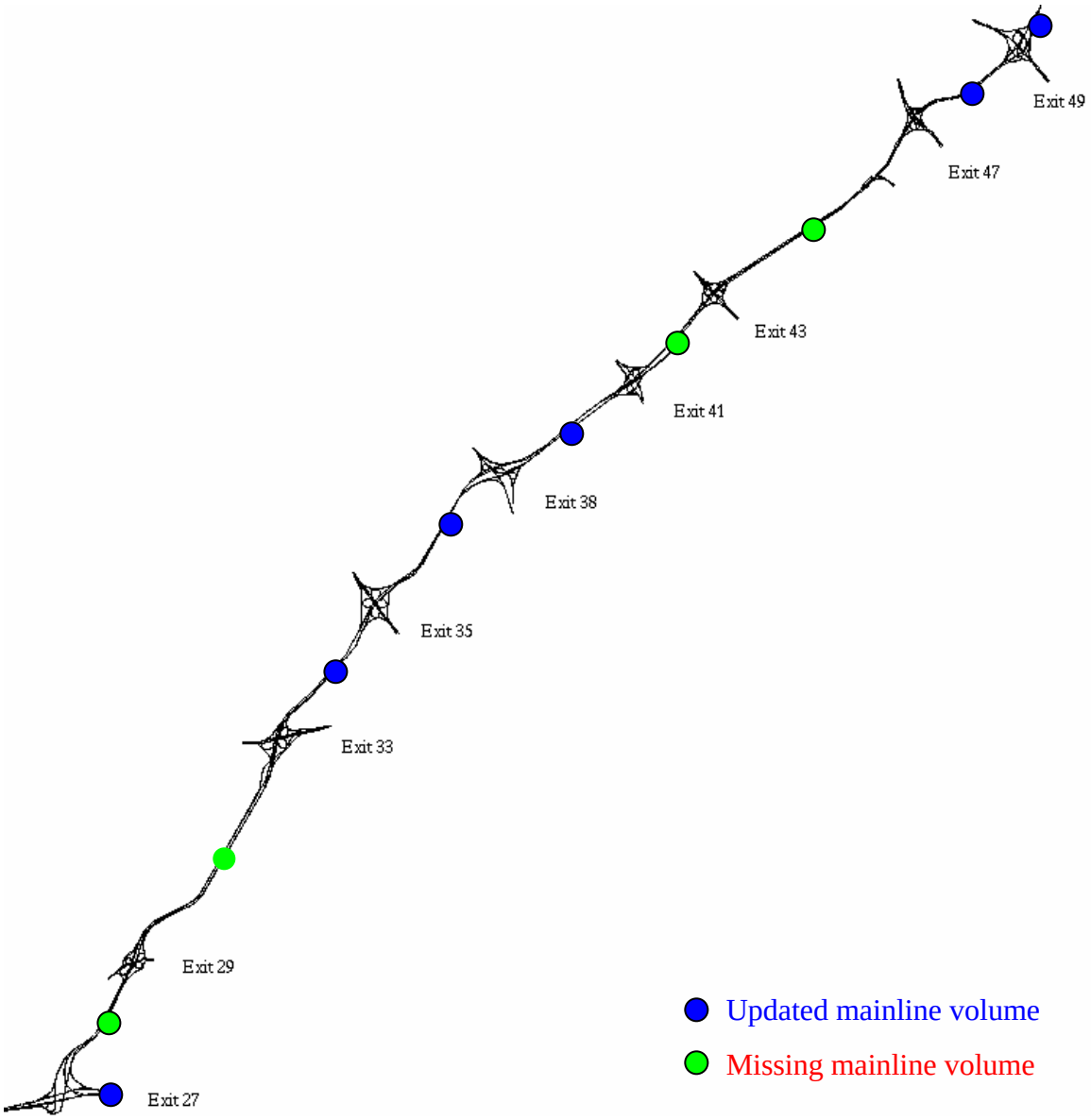


Figure 5-3: An Example Network for Case Study 2

The estimation results for Case 2 using the same methodology are summarized in Table 5-2, where mainline segments 2, 3, 7, and 8 do not have any detector stations. It is noteworthy that the maximum difference between detected volumes and actual volumes is 2.38%, offering the potential for applying this in practice.

Table 5-2: Comparison between the estimated and actual mainline volumes in Case 2 with Algorithm-1

Location	Actual Volume	Detected Volume	Difference
2	5120	5008	2.19%
3	4693	4637	1.19%
7	5527	5487	0.72%
8	5578	5445	***2.38%***

Highway facilities without extensive coverage of sensors or any available historical volumes should not be collected from the same time period as assumed in the previous examples. For instance, it is likely that the highway system may have:

- Single historical volumes on each location but from different time periods;
- Multiple historical volumes on some mainline links or ramps; or
- No historical volume for some particular locations.

To contend with the above complex scenarios, this study has developed a generalized algorithm, called Algorithm-2, to provide the best estimate for missing volumes based on information from different sources and inconsistent qualities.

5.3 Algorithm-2 for a Generalized Scenario

In order to implement Algorithm-2, the generalized scenario can be described as follows:

- Some mainline links have detector stations, and their traffic volumes from the current time interval T (e.g., 7-8 a.m.) of Day t back to the past P months (e.g. the past 12 months) are available for references and estimation.
- The remaining mainline links and ramps have only limited historical volume data, and their volumes at time interval T are needed and have to be estimated with volume data at neighboring freeway locations.

Algorithm-2 is designed to provide estimated volumes at time interval T for those locations or ramps without detectors. The core logic of this estimation algorithm consists of the following steps:

1. Identify one or more nearby detector stations that are most likely to have highly correlated traffic patterns with each mainline or ramp volumes that are to be estimated.
2. Use each identified detector as a reference set, and estimate its historical annual average volume and seasonal variation using the most likely method.
3. Set the average volume at the target T period and its seasonal variance as the "*reference pattern*" for nearby locations with limited historical volumes.
4. Project the traffic volume at the target T period for those locations having only limited historical volumes, based on their own historical volume data and the "reference pattern" at nearby detector stations.
5. Formulate the relationships between detected volumes at the target time period *T* and those estimated volumes, based on the traffic flow conservation relation at each freeway interchange;
6. Solve the formulated optimization model using the least square approach to ensure that the distribution of all estimated traffic volumes are consistent with their spatial interrelations and detected volumes.

Step-2:

The mathematical model used in Step-2 is based on the following assumptions:

- The mean volume μ_i of a detector station for the time period T follows a random process in its day-to-day fluctuation, but its variance σ^2 remains unchanged from year to year.
- A seasonal variation pattern around the mean volume exists, which are modeled as adjustment factors, $\lambda_1\ \lambda_2, \lambda_3, \lambda_4$ for each season, and those factors remain constant over the past several years.

Under these assumptions, the maximum likelihood function is given:

$$L(\theta \mid v) = \prod_i \prod_j \prod_k f(v_{ijk} \mid \theta)$$

$$= \prod_i \prod_j \prod_k \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{1}{2}(\frac{v_{ijk} - \mu_i - \lambda_j}{\sigma})^2]$$

$$= \frac{1}{\sigma^N \sqrt{2\pi}^N} \exp[-\frac{1}{2}\sum_i \sum_j \sum_k (\frac{v_{ijk} - \mu_i - \lambda_j}{\sigma})^2]$$

(5-2)

Where:

i : is the target year during which the volume data have been collected;

j : indicates the season during which the volume data have been collected;

(Let $\lambda_1 \equiv 0$ for the first season to standardize the formulation);

k : denotes the date during which the volume data have been collected; and

N : is the total number of available and reliable data sets used for estimation.

The log likelihood function for Equation 5-1 is defined as follows:

$$\log L(\theta \mid v) = -\frac{1}{2}\sum_i \sum_j \sum_k (\frac{v_{ijk} - \mu_i - \lambda_j}{\sigma})^2 - N \log \sigma - \frac{N}{2} \log 2\pi$$

(5-3)

To find the maximum likelihood estimator of μ_i, λ_j, one can set the partial deviation to equal zero, then, the estimated parameters can be obtained by solving the following set of equations:

$$\frac{\partial \log L(\theta \mid v)}{\partial \mu_i} = \frac{1}{2}\sum_j \sum_k \frac{2}{\sigma} \times \frac{v_{ijk} - \mu_i - \lambda_j}{\sigma} = \frac{1}{\sigma^2}\sum_j \sum_k (v_{ijk} - \mu_i - \lambda_j) = 0$$

$$\frac{\partial \log L(\theta \mid v)}{\partial \lambda_j} = \frac{1}{2}\sum_i \sum_k \frac{2}{\sigma} \times \frac{v_{ijk} - \mu_i - \lambda_j}{\sigma} = \frac{1}{\sigma^2}\sum_i \sum_k (v_{ijk} - \mu_i - \lambda_j) = 0$$

(5-4)

Step-4:

Using the set of parameters estimated in Equation 5-4 as the "reference pattern", one can then perform Step-4 for projecting the estimated volume for those locations having only historical data. The assumptions embedded in Step-4 are stated below:

- The mean volume μ'_i and seasonal variation factors at those locations without detectors follows the same pattern as that of the nearest detector stations which have been estimated using Equation 5-4.
- The variance σ'^2 that reflects the day-to-day volume fluctuation remains unchanged over time.

With above assumptions, one can construct the maximum likelihood function as follows:

$$
\begin{aligned}
L(\theta' | v') &= \prod_i \prod_j \prod_k f(v'_{ijk} | \theta') \\
&= \prod_i \prod_j \prod_k \frac{1}{\sigma' \sqrt{2\pi}} \exp[-\frac{1}{2}(\frac{v'_{ijk} - \mu'_i - \lambda'_j}{\sigma'})^2] \\
&= \frac{1}{\sigma'^N \sqrt{2\pi}^N} \exp[-\frac{1}{2} \sum_i \sum_j \sum_k (\frac{v'_{ijk} - \mu'_i - \lambda'_j}{\sigma'})^2]
\end{aligned}
\tag{5-5}
$$

Where:

$\mu'_i = \mu'_{ini} \times \mu_i / \mu_{ini}$

$\lambda'_j = \lambda'_2 \times \lambda_j / \lambda_2$

ini : is the earliest year of the available historical volume data;

i : is the available historical volume in year i;

j : is the season during which the volume data have been collected;

k : is the specified date during which the volume data have been collected; and

N : is the total number of data sets used for volume estimation.

Note that care should be exercised in using the above algorithms. For example:

- If a location has sufficient historical data, then one can use its own traffic evolution pattern to compute the seasonal variation factors, rather than use the pattern at its nearest detector location.

- If a location has only one historical data, this algorithm cannot be applied. The volume can be adjusted based on the variation pattern at its nearest detector location.

Step 5 and Step 6:

The above Steps 5 and 6 are designed to refine the projected volume for each location without a detector station. This is due to the reason that the volume for such locations at the target time period T is projected independently based on their own historical data and traffic patterns at the nearest detector stations. Thus, the independently projected volumes at interchanges may not be consistent with the traffic flow conservation relations; the total in-flows should be equal to the total out-flows. The formulation presented hereafter is proposed to ensure that all projected volumes are consistent with their spatial interrelations in the freeway network.

The objective function:

- Minimize the sum of differences between the initially projected and final estimated volumes:

$$\min Z = \sum_i (v_i^{est} - v_i^{pro})^2 \tag{5-6}$$

Where:

i : is the set of locations other than detector stations;

v_i^{est} : is the final estimated volumes in these locations without detectors; and

v_i^{pro} : is the initially projected volumes in these locations without detectors.

The main model constraints can be constructed based on flow conservation relations on mainline links, as shown in Figure 5-4.

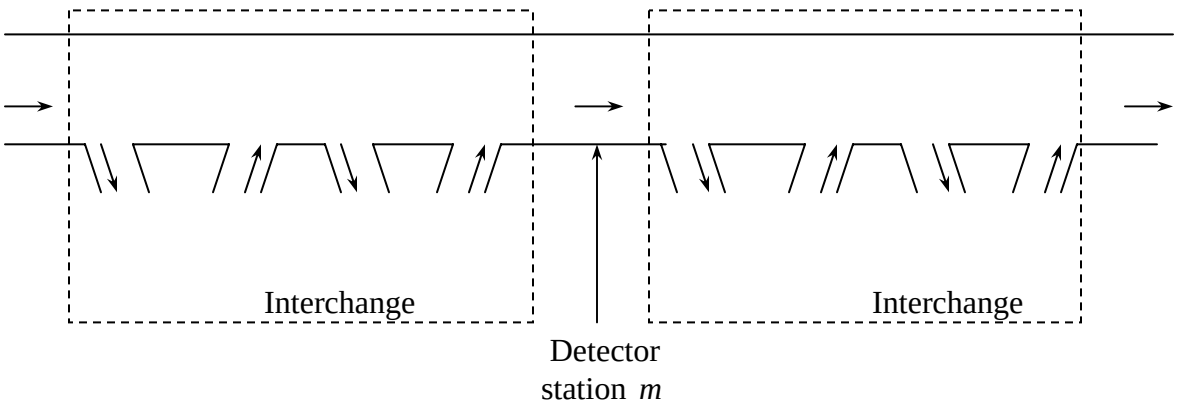


Figure 5-4: A Graphical Illustration of Flow Conservation on a Freeway Segment

Based on the flow relations in Figure 5-4, following two constraints are constructed:

$$v_{i-1}^{main} - v_{i,1}^{off} + v_{i,1}^{on} - v_{i,2}^{off} + v_{i,2}^{on} = v_i^{main} \tag{5-7}$$

$$v_i^{main} - v_{i+1,1}^{off} + v_{i+1,1}^{on} - v_{i+1,2}^{off} + v_{i+1,2}^{on} = v_{i+1}^{main} \tag{5-8}$$

Where:

v_p^{main} :is the volume on mainline link p during the target time interval;

$v_{p,n}^{on}$:is the volume on the *n-th* on-ramp at interchange p during the target interval; and

$v_{p,n}^{off}$:is the volume on the *n-th* off-ramp at interchange p during the target interval.

If detector station m is located on the mainline link i, then v_i^{main} is equal to v_m^{cs}, which is the volume observed at detector station m during the target interval.

Users can specify a feasible range for those estimated volumes, and formulate ranges such as the following model constraints:

$$v_i^{est} \le v_i^{\max}, \text{ and } v_i^{est} \ge v_i^{\min} \tag{5-9}$$

With the above model, one can employ any optimization algorithm to generate a set of refined volumes that are consistent with their spatial interrelations on the freeway segment.

5.4 Illustration of the Interface Functions

To support the above function for estimating missing volumes, the proposed Integrate Traffic Information and Simulation System (ITIS) offers the following interface functions to facilitate its applications:

1. Evaluating the need for volume estimation.

When the system receives a request to execute the simulation, this function will automatically search the database to examine the volume availability. If all the volumes during the specified simulation period in the target network are available, the system will transfer this information to the simulation module and activate the execution function. Otherwise, the system will activate the interface for the volume estimation module, as shown in Figure 5-6.

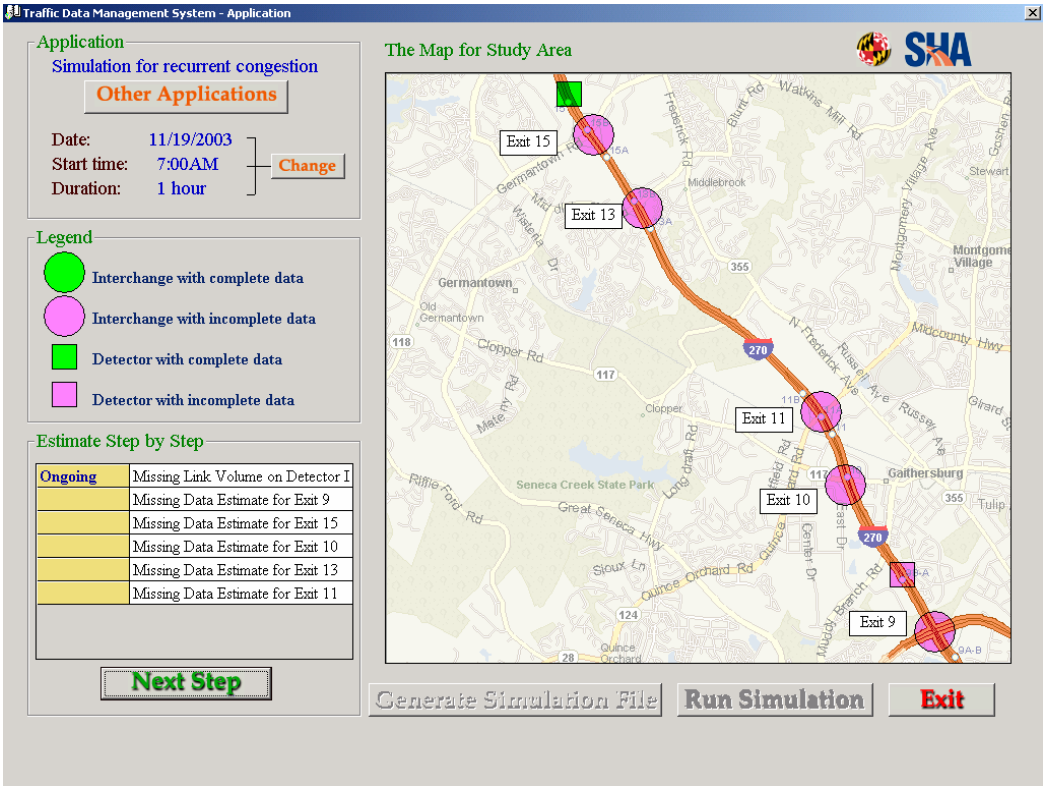


Figure 5-6: Interface for the Volume Estimation Module

The interface for this function includes:

- **"A Map for the Study Area"**: on the right side of the interface to display the target network.
- **"Application"**: in the top left corner to define the simulation time and duration.
- **"Legend"**: right below the **"Application"** section to indicate the data availability.
- **"Estimate Step by Step"**: in the lower left corner to display the list of locations with missing volumes.

2. The interface for volume imputation.

The proposed ITIS also offers a function that is capable of estimating missing volumes for detector stations. For example, a detector station may not function properly during some time periods, and produce either no data or unreliable information. One can then use the function provided by the ITIS to compute that missing data. Since the employed estimation algorithm is a standard time-series statistical model and available in

most literature, this chapter does not intend to present its formulation, and illustrates only the following embedded interface features.

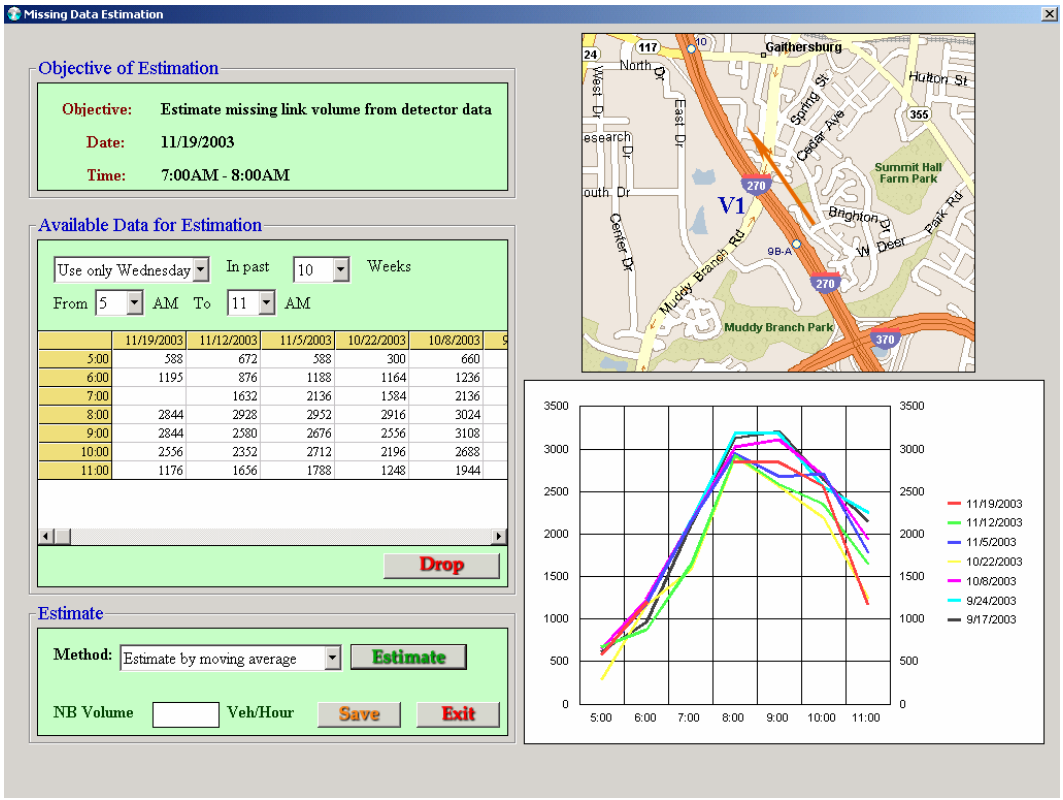


Figure 5-7: Interface for Detector Station Volume Imputation

Figure 5-7 presents the main interface components for this function, which includes:

- **"Objective of Estimation"**: defining the specified date and time of the volume to be imputed, where the location of the detector station is illustrated in the top right corner.
- **"Available Data for Estimation"**: including the day of week and hours of available data, which are elaborated in both the table and the figure in the lower right corner.

By selecting a specific record and clicking the "Drop" button, users can delete the record from the data set.

- **"Estimate"**: in the lower left corner lists available methods and estimated results.

If the results are acceptable, the user can save such information to the database by clicking the "Save" button as shown in Figure 5-8.

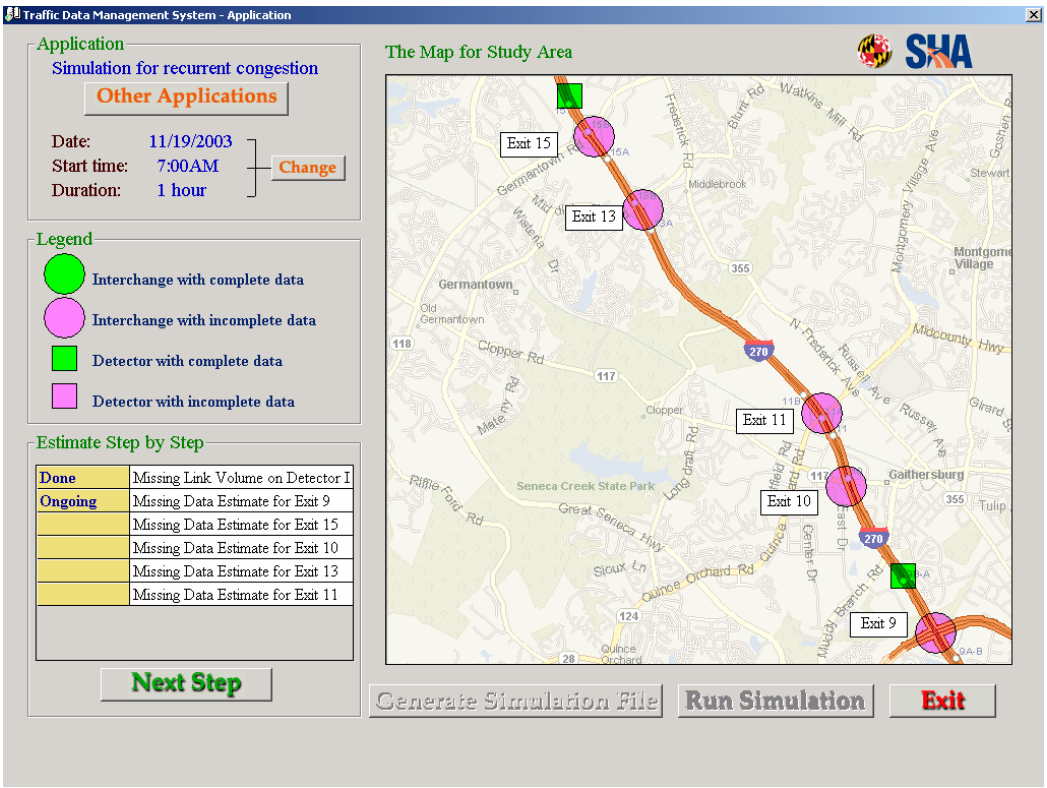


Figure 5-8:The Interface After Performing One Step of Estimation.

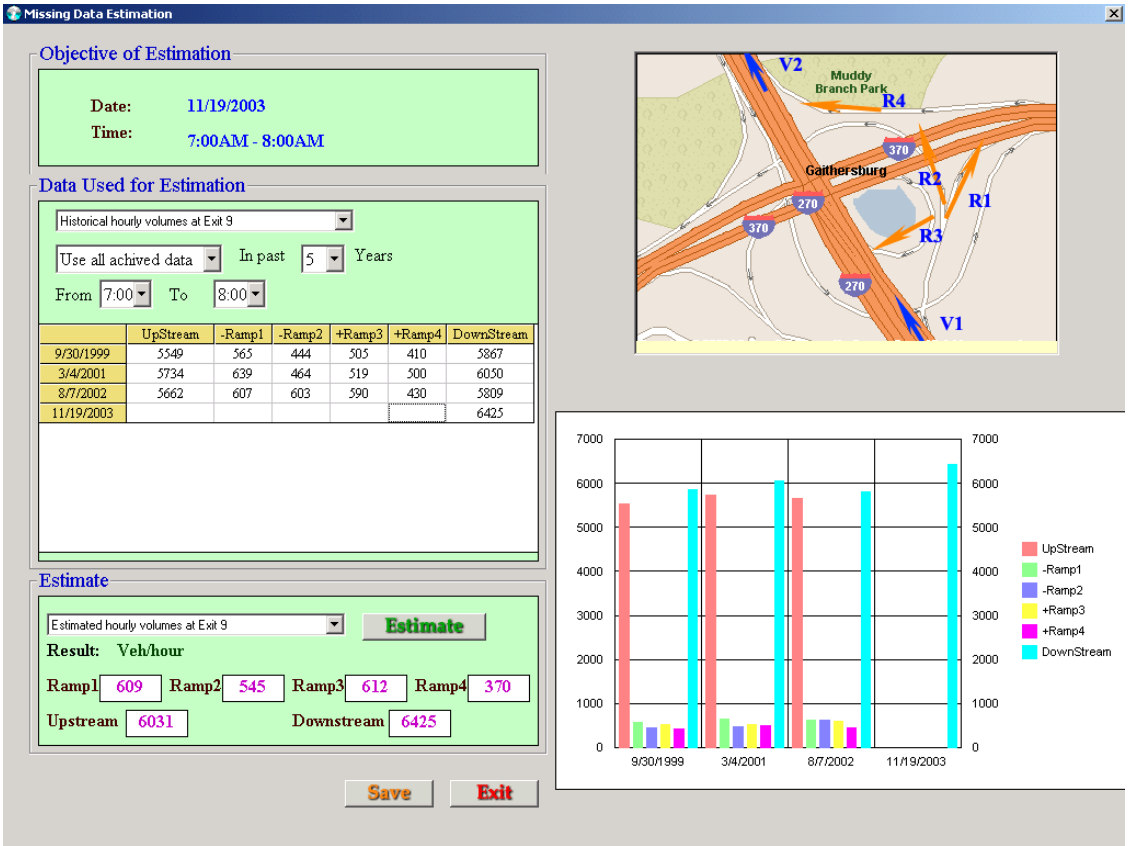


Figure 5-9: Interface for Estimating Volume at Locations Without Detector Stations

3. The interface for missing volume estimation

Figure 5-9 presents the interface for estimating volumes at locations other than those having detector stations. The interface for this function includes the following parts:

- **"Objective of Estimation"**: in the top left corner to define the specified date and time of the volumes to be estimated.
- **"Data Used for Estimation"**: to indicate the data sources, such as the day of week and the year of available data, which are illustrated in the table and the figure in the right corner.
- **"Estimate"**: in the left corner to provide estimated volumes with the selected algorithm for all locations other than those having detector stations.

Similarly, if the estimated results are acceptable, the user can save the information to the database by clicking the "Save" button as shown in Figure 5-10.

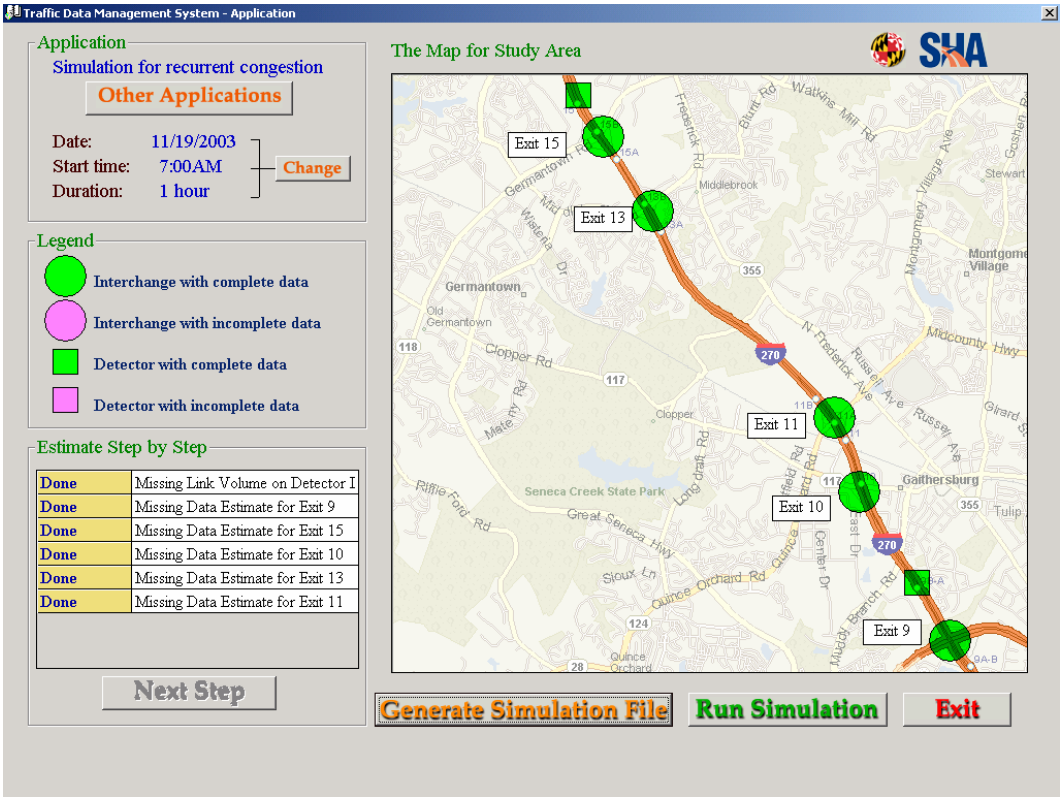


Figure 5-10: The Interface After All Missing Volumes Have Been Estimated

If all locations in the section of "**Estimation Step by Step**" have been marked "**Done**", it indicates that the volume set for simulation analysis has been successfully constructed. The simulation can then be activated by pressing the buttons "**Generate Simulation File**" and "**Run Simulation**".

Chapter 6
An Advanced Application Model for Traffic Management

6.1 Description of Key Module Features

This chapter presents the key features of the proposed Advanced Application Module for Traffic Management (ATM) that is designed to assist traffic engineers/operators in estimating traffic impacts, evaluating operational strategies, and projecting traffic conditions during both recurrent and non-recurrent congestion. The ATM module with its simulation, statistical inferences, and supplemental components can offer the following functions for traffic management:

- Travel time estimation during recurrent and non-recurrent congestion periods;
- Incident impact analysis and evaluation of detour operations;
- Work zone control and analysis; and
- Special event management.

Each of the above key functions is described briefly below:

- Travel time estimation function

Reliable estimation of travel times for either recurrent or non-recurrent congestion is a difficult but imperative task, as more and more commuters have demanded responsible highway agencies to provide such information in view of the deteriorating traffic conditions and the resulting uncertainties. However, to predict the travel time for a target highway facility at an acceptable level of accuracy in a timely manner generally requires an extensive set of traffic information over a long time period. The travel time estimation function in the ATM module offers the following three methods for its applications:

- *Simple average from available historical data under similar traffic conditions*, such as on the same segment during the same time interval, and same day of a week over the previously specified time period (e.g. recent two months). This method can yield a sufficiently reliable travel time for recurrent traffic conditions, especially if extensive historical data are available at most locations of interest.

- *Statistical Methods based on the historical data*. This method features its use of all historical data available from locations with similar traffic patterns and volume levels. It is especially useful for highway facilities with limited surveillance sensors and historical traffic condition data.

- *Simulation Method:* This approach is recommended for use in a relatively large area or a long commuting corridor where traffic sensors are not sufficient for direct computation of travel time or traffic speed. The simulator (e.g., I-270/MD 355 simulator) for such applications needs to be calibrated with extensive off-line data. With a module to constantly update its database and perform the calibration from available information, simulation can be the most flexible and powerful tool for use in estimating travel time at the network level.

The travel time function available from the ATM module can also be used to interact with on-line traffic sensors and to perform travel time estimation in real-time operations. Its applications, however, necessitates the activation of the other supplemental modules. Principal steps involved in real-time predictions of network traffic times are summarized below.

- *Real-time prediction of travel time during recurrent congestion with simulation*

Step-1: provide the initial estimate of travel times with any of the aforementioned three methods, and up-to-date traffic information in the database.

Step-2: collect and compile all available volume (or flow rate) data from on-line traffic sensors.

Step-3: compare the difference between the on-line available volumes with those available off-line for use in the Step-1 travel time estimation.

Step-4: keep the initially estimated travel times and go back to step-1, if the differences are within an acceptable range; otherwise, go to Step-5.

Step-5: use the method designed for missing volume estimation to update the volume at those locations without traffic sensors, based on the initial base-line volume information for each location in the simulator and on-line sensors form limited surveillance stations.

Step-6: re-execute the simulator with on-line updated volumes, and produce the updated travel time information for the target highway segments.

Step-7: repeat the procedures between Step-2 and Step-6 to constantly update the predicted travel times for real-time traffic management.

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- Incident management function

This function is designed to assist traffic engineers in performing the following tasks during the response and clearance of reported incidents:

- Estimate the required duration to clear the incident and recover the traffic condition, based on the detected incident nature, location, congestion level, and weather information.
- Project the evolution of traffic queue length, and the impacted area due to incident related operations;
- Compute the delay and travel time for drivers trapped in the incident impacted area; and
- Evaluate the effectiveness of candidate traffic management plans for incident management such as ramp metering and detouring operations.

- Work zone simulation function

Different from incident management, this function is typically used in off-line planning applications. With such a function, responsible traffic engineers/planners can evaluate the impacts of different work zone operational plans, and select the most cost-benefit alternative, based on the resulting delays, average flow speed, maximum queue length, and operating costs.

- Special-event management function

The focus of this function is to offer responsible engineers/staff an effective tool for estimating the duration needed to evacuate a large volume of traffic during either emergency or pre-planned activities such as football games. This function can automatically activate the network simulator, based on the target area for evacuation and the proposed diversion plan. It will produce the following information for evaluation:

- Average speed over time in each evacuation route;
- Average delay on each control point, typically at either major intersections or interchanges;
- Travel time on each route within the control boundaries;
- Total time needed to evacuate the entire traffic demand;
- Effectiveness of any proposed traffic control plan during the evacuation.

6.2 Example Applications

This section uses two examples to illustrate the procedures for travel time estimation during recurrent congestion, and incident impact assignment during non-recurrent congestion.

- Travel time estimation

Figure 6-1 shows the main menu for the Advance applications module for Traffic Management (ATM), where users will start the travel time estimation by clicking the designated icon.

Figure 6-1: The main menu of the ATM module

Depending on the availability of data associated with the target highway, one can select one of the following methods for travel time estimation: simulation approach, average of historical data, and statistical models (see Figure 6-2). These three approaches

can provide estimation of travel time at a different level of accuracy and execution time. Each of these three approaches is briefly discussed below.

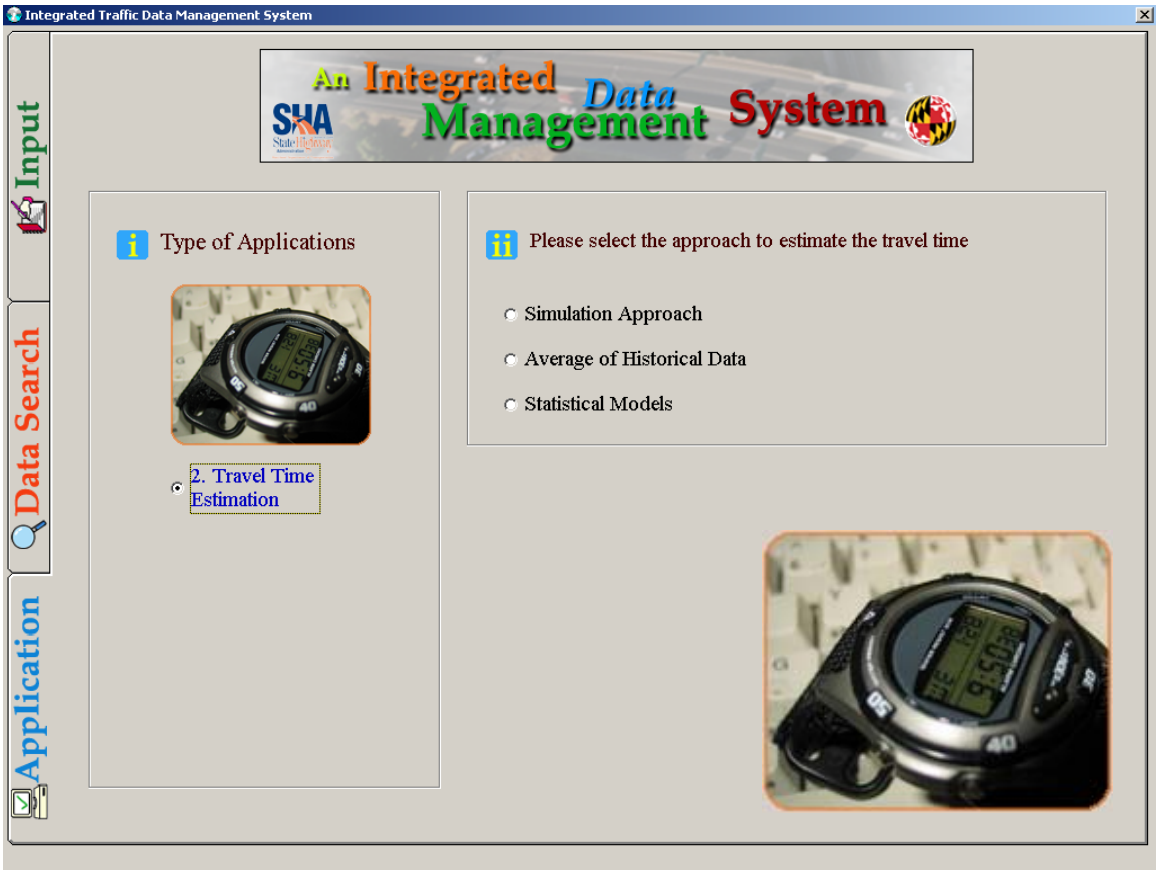

Figure 6-2: Three approaches for the travel time estimation

- **Average of historical data**

It provides the estimated travel time based on the average over the historical data on the same roadway segment and during the same time periods. The user can also specify the range of data for use in estimation, such as the same weekday over the past 2 years. This approach has the shortest execution time, and can be quiet effective if sufficient historical data are available and traffic conditions are relatively stable from day to day. Otherwise, one shall use either the statistical or the simulation method.

- **Statistical approach**

This method is designed for those familiar with statistical techniques, but for some reasons unable to use traffic simulation models. Typical statistical approaches available for travel time estimation include:

- Moving-average method, where the estimated travel time is a weighted average of travel times during the same period over the past several days or weeks, depending on the data availability.
- Time-series method, where the estimated travel time is a function of travel times over the past several time intervals on the same day and previous days (or weeks). It can take into account the weekly and seasonal patterns in the model if data are available. A detailed description of those statistical methods is available in most statistical literature.

- **Simulation approach**

This approach is to take advantage of the embedded simulator and its capability in estimating the data for those locations without on-line detectors. However, this approach takes a longer execution time and a larger storage space than the previous two approaches.

The following example presents the procedures for analyzing the recurrent congestion with the simulation approach. By selecting the simulation icon from the main interface for recurrent congestion, users will be asked to input the simulation starting time, duration, and the target study segment as shown in Figure 6-3.

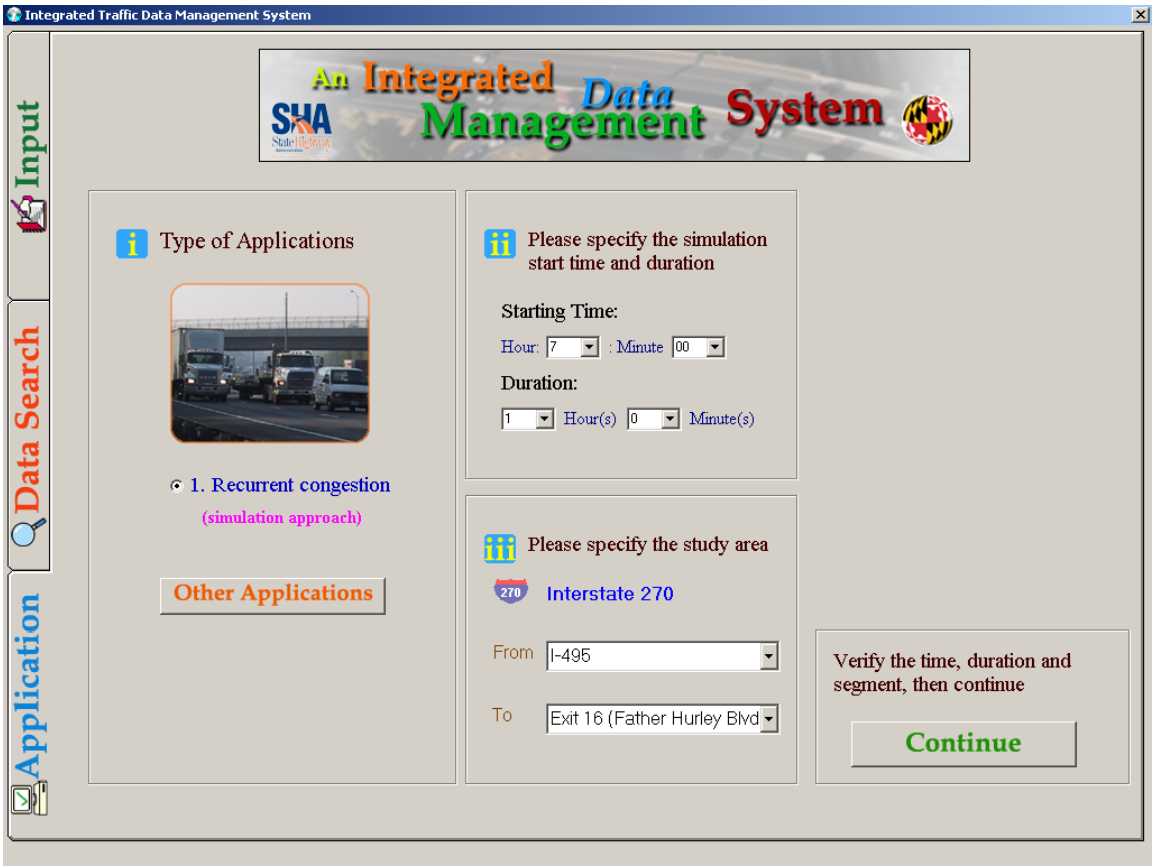

Figure 6-3: The interface for estimating travel time with simulation

Figure 6-4 presents the output screen of the travel time estimation with the above three methods. Potential users can select the departure time, the trip origin and travel time of the target highway segments from the displayed tables. Note that the estimated traffic conditions are displayed with colors, based on their projected traffic flow speeds.

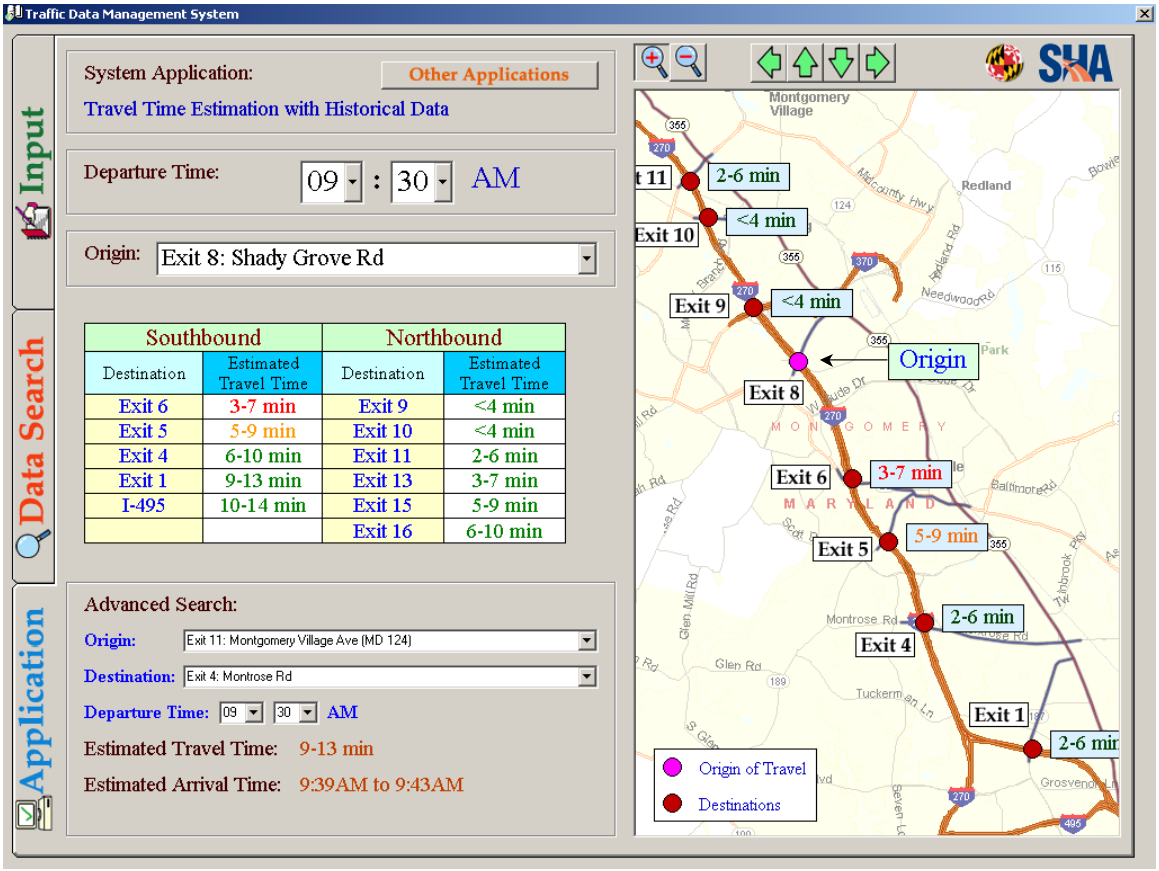

Figure 6-4: Display format for the estimated travel time

The system also provides the function for users to compute and display the travel time between an O-D pair over a specified time period. Depending on the purpose of application, one may request the system to display the speed on each target segment, rather than the travel time (see Figure 6-5).

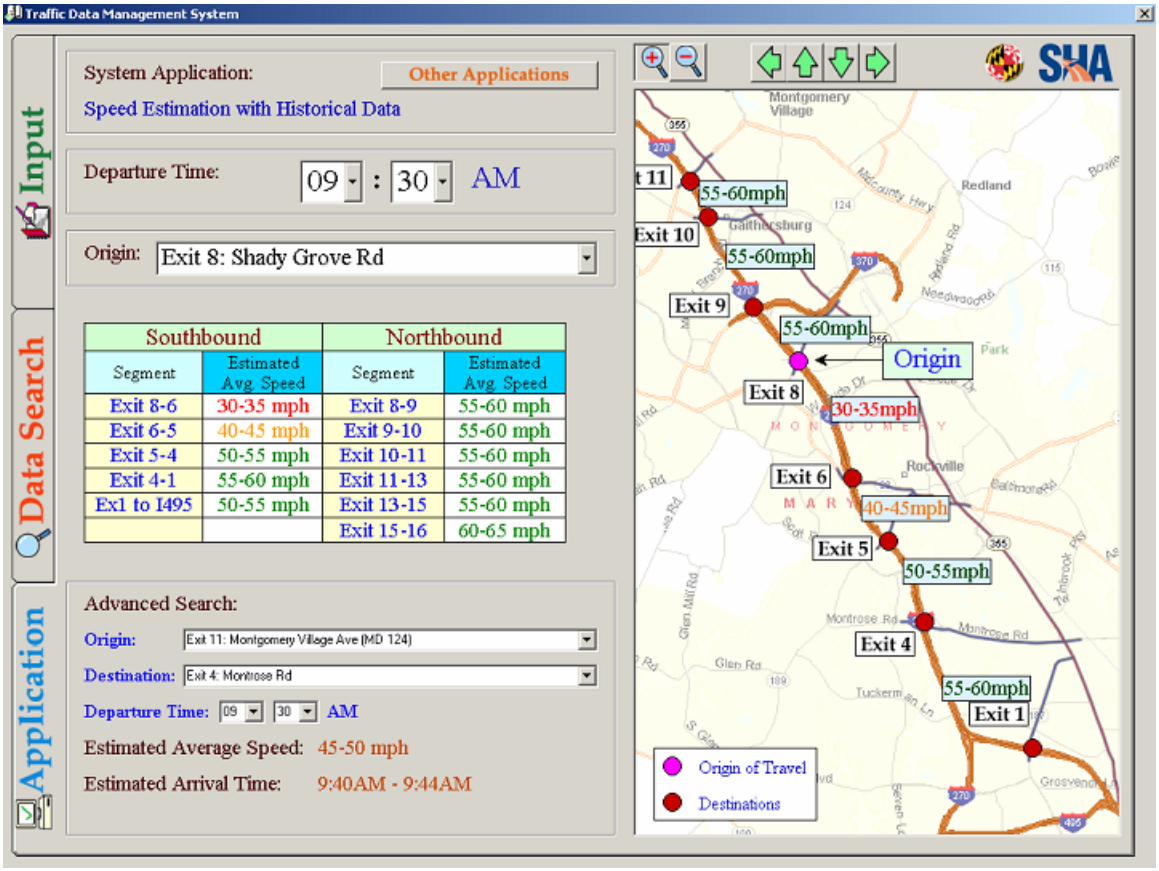

Figure 6-5: An example Output for the estimated average speed

Prior to the execution of simulation, the embedded function for the missing data estimation will first review the available data for the target highway segment, and determine if it is necessary to perform any estimation. (see Figure 6-6)

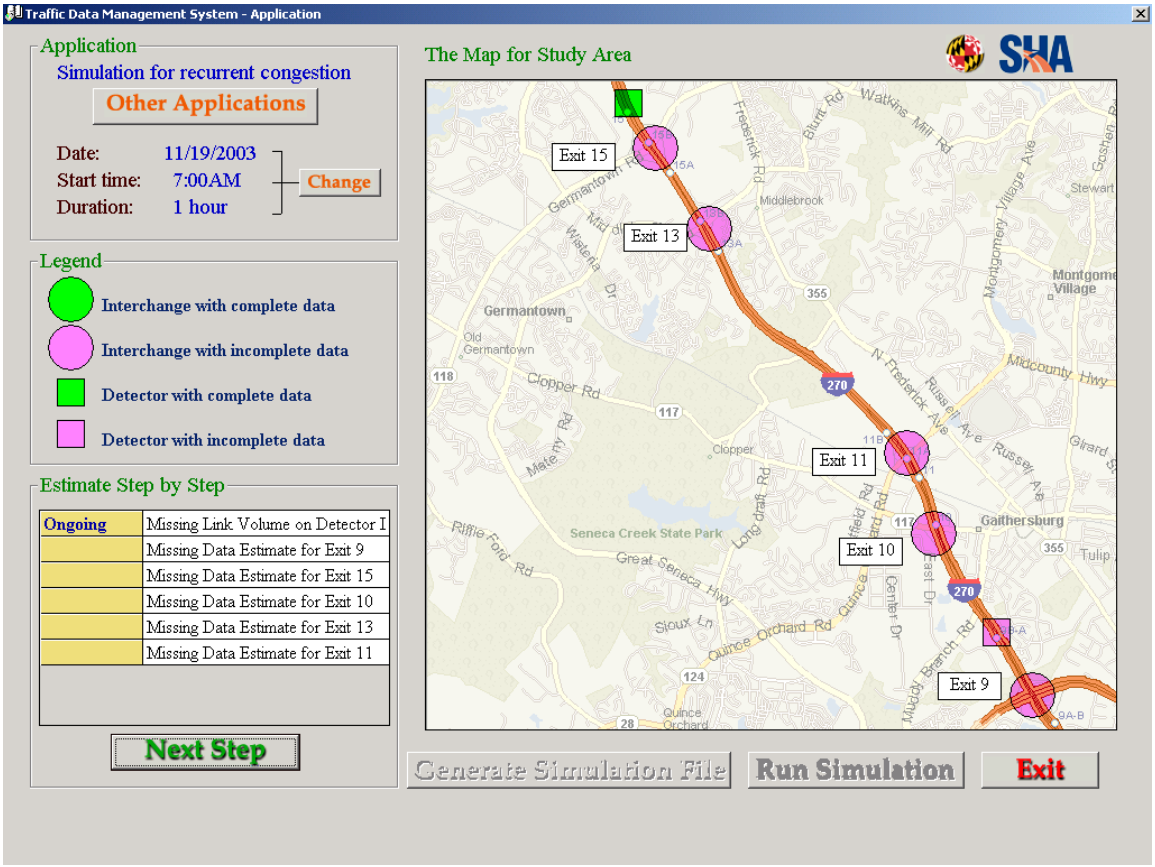

Figure 6-6: Main interface for the missing data estimation

Figure 6-6 presents the example interface to display these locations that do not have a complete set of volume data for simulation analysis. The system will perform estimation of missing volumes in sequence, based on available on-line and off-line data in the target area for simulation. Figure 6-7 shows the interface for estimating the missing data, where users can set the criteria to search for available data. For example, one may decide to use only these archive data on the same weekday over the same period for volume estimation.

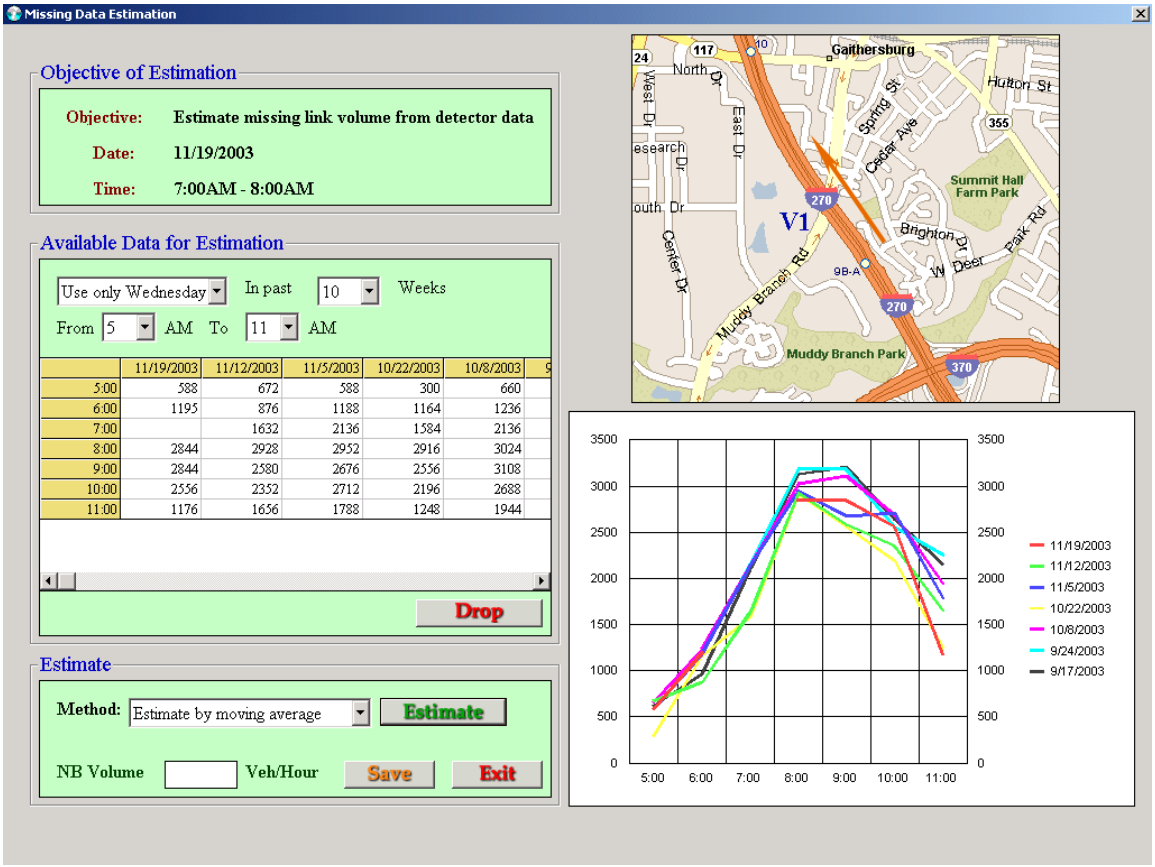

Figure 6-7: The interface for missing data estimation

After setting all the inputs for missing data estimation, including data range and the estimation method, users can execute the estimation by clicking the **"Estimate"** button (see Figure 6-8).

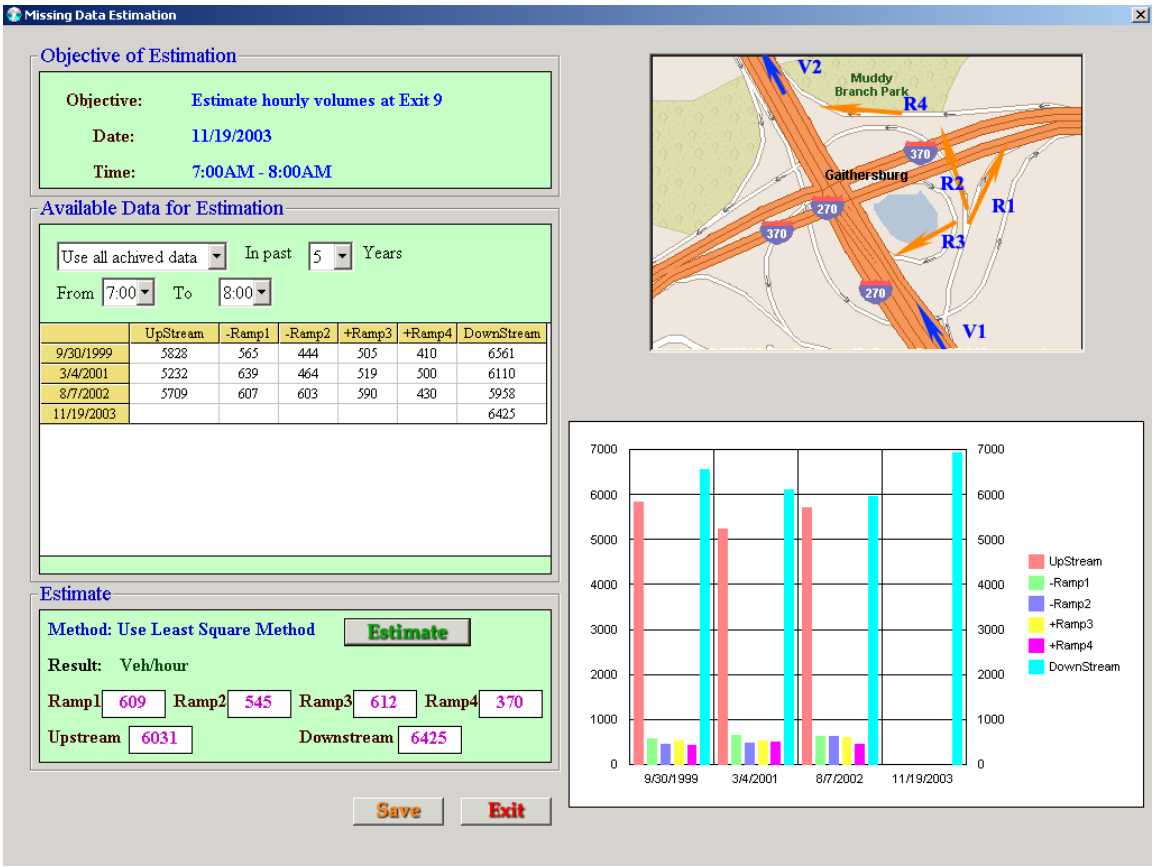

Figure 6-8: The Interface showing the estimated results

Figure 6-9 shows some snapshots of the interface after all missing volumes have been estimated. The progress of the missing data estimation will be displayed automatically with colors, until the system has all needed data to generate the input file for simulation analysis.

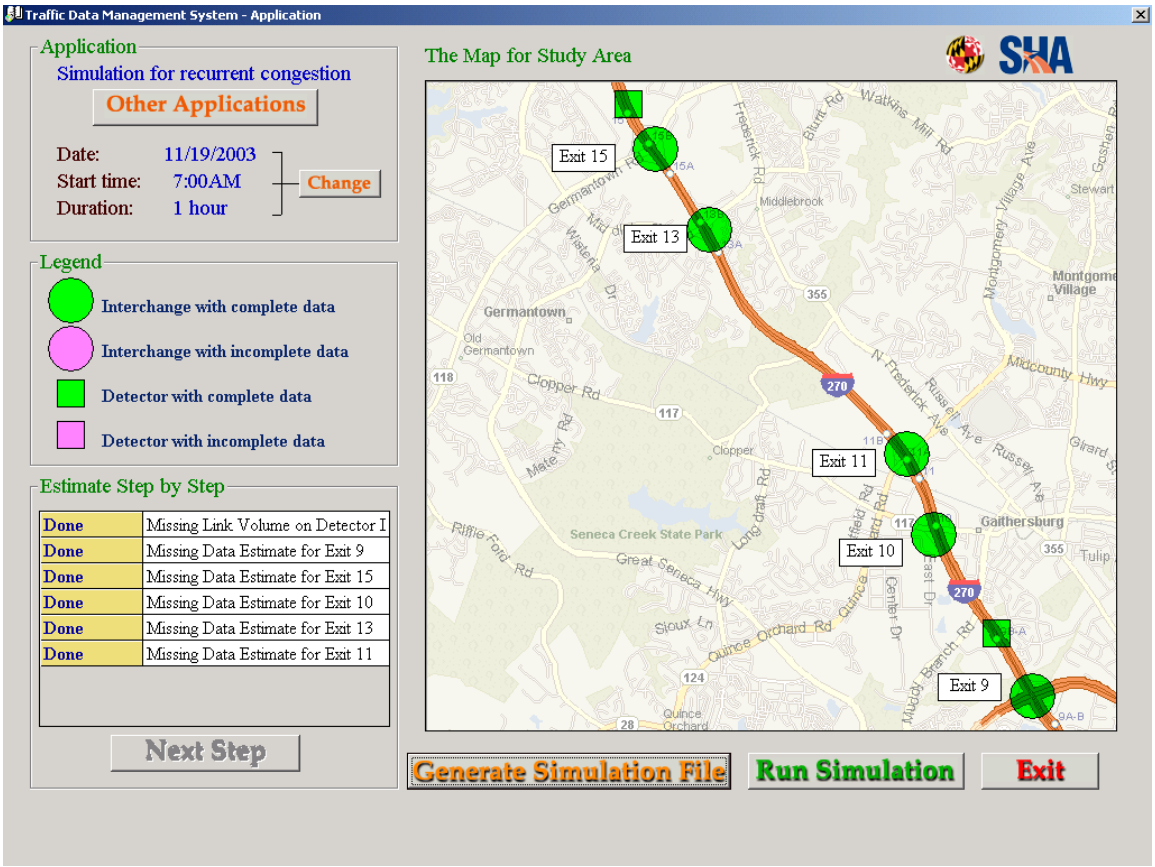

Figure 6-9: the interface to show that missing volumes have been estimated

- Incident Management

The advanced module for traffic management can take advantage of the system's embedded simulator for incident management. For example, with I-270/MD 355 simulator, one can estimate the duration of a detected incident, predict the maximum queue length, and project the evaluation of congestion patterns as well as the resulting delay, based on available incident related information. An example application of real-time incident management with the proposed advance module for traffic management is provided below.

Given Incident Scenario for the CHART incident response team:

At 9:25AM, an incident occurred on the southbound I-270 between Exit 4 and Exit 1. Two right lanes have been blocked. The location of the incident is about 4996 feet south of Exit 4.

Application procedures:

Step 1: Execute the incident management function provided by the ATM module.

Step 2: Zoom in the interface map to the segment of the I-270/MD 355 corridor between Exit 1 and Exit 4, and click the map to identify the incident area (see Figure 6-10 and Figure 6-11).

Step 3: Input information related to the detected incident through the following questions:

- Which direction of the traffic is being blocked?
- Where is the incident location (as shown in figure 6-13)?
- Which lanes have been blocked?
- What is the estimated incident duration?

Note that to assist responsible staff in estimating the incident duration, this module will activate the database in the system, and display all previous incidents at the same or nearby locations during the same period. Users can then either make their own estimate of the required incident duration, or let the embedded knowledge-base module to perform its estimation (see Figure 6-15)

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

Step 5: Execute the simulation.

Step 6: View either the chart-based (see Figure 6-18) or map-based (see Figure 6-19) output displays.

Step 7: Perform the detour operation (see Figure 6-20) and reset signal phases and settings on the detour routes (see Figure 6-21 and Figure 6-22).

Step 8: Perform simulation again and evaluate the effectiveness of the proposed detour operation (see Figure 6-23).

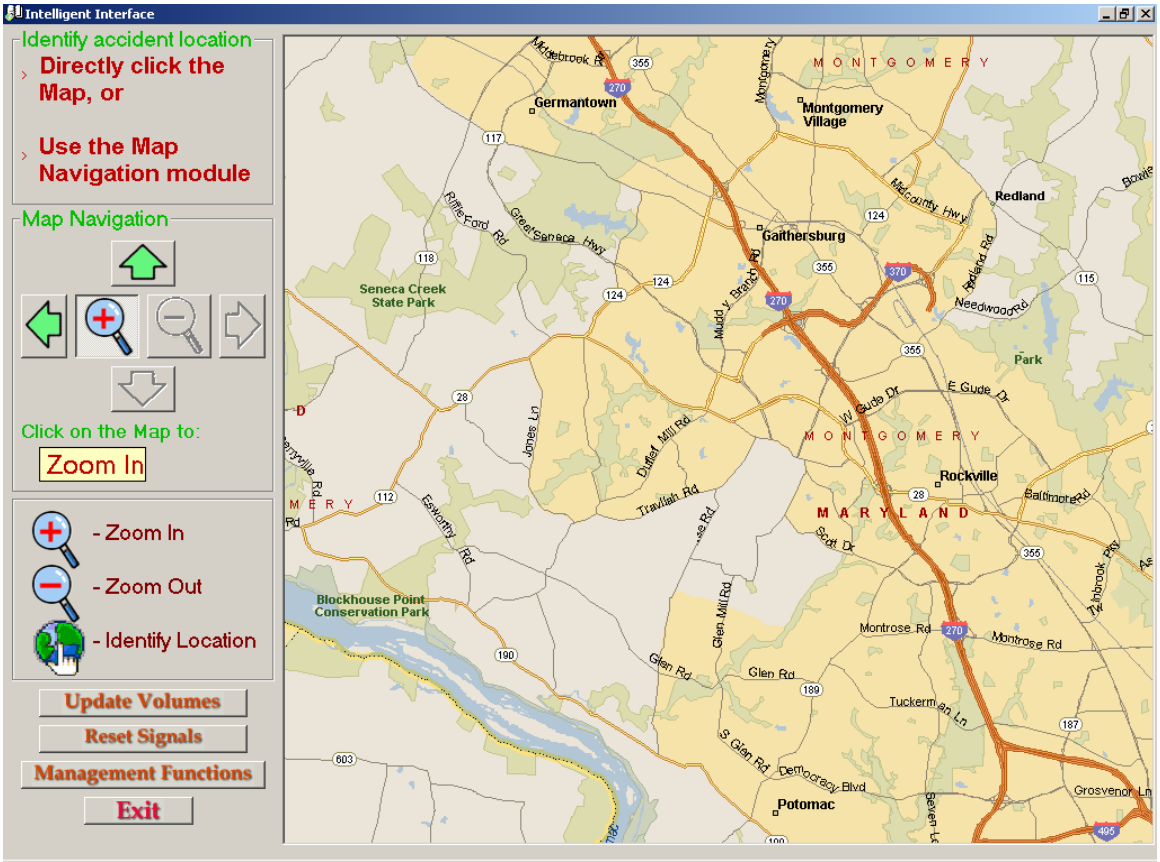

Figure 6-10: An interface map of the I-270/MD 355 corridor displayed by the simulator

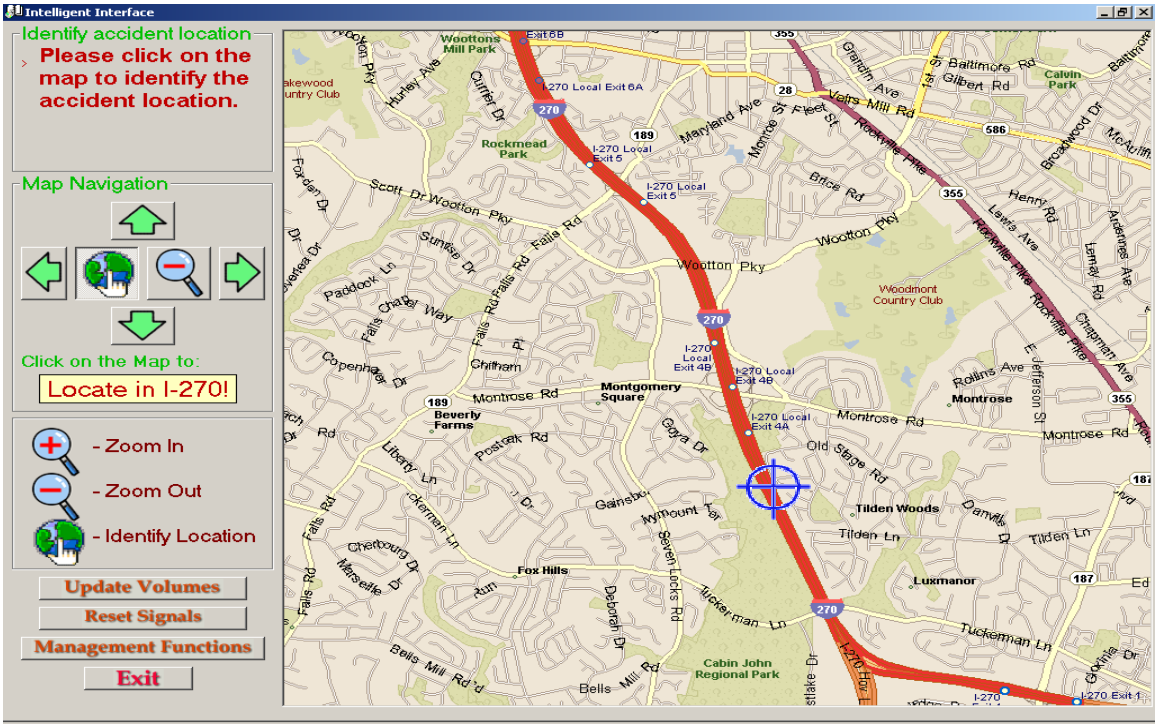

Figure 6-11: A detailed view for the target segment between Exit 1 and 4 on I-270

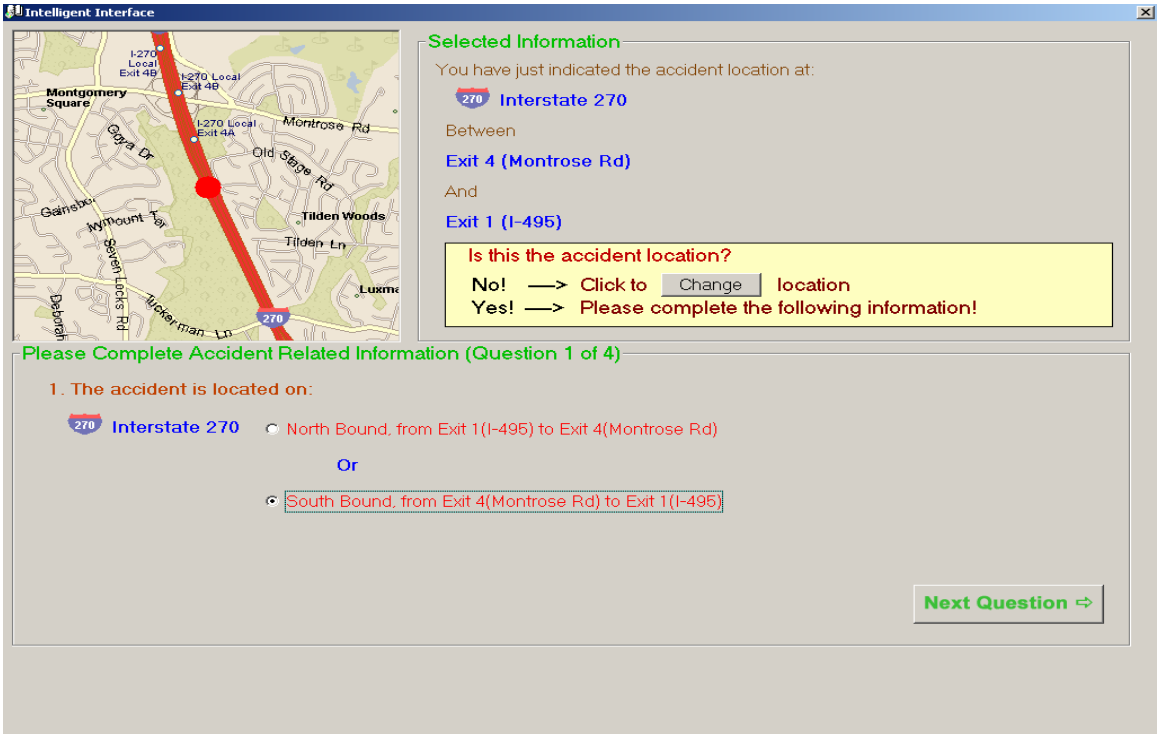

Figure 6-12: The interface for users to input the blocked traffic direction

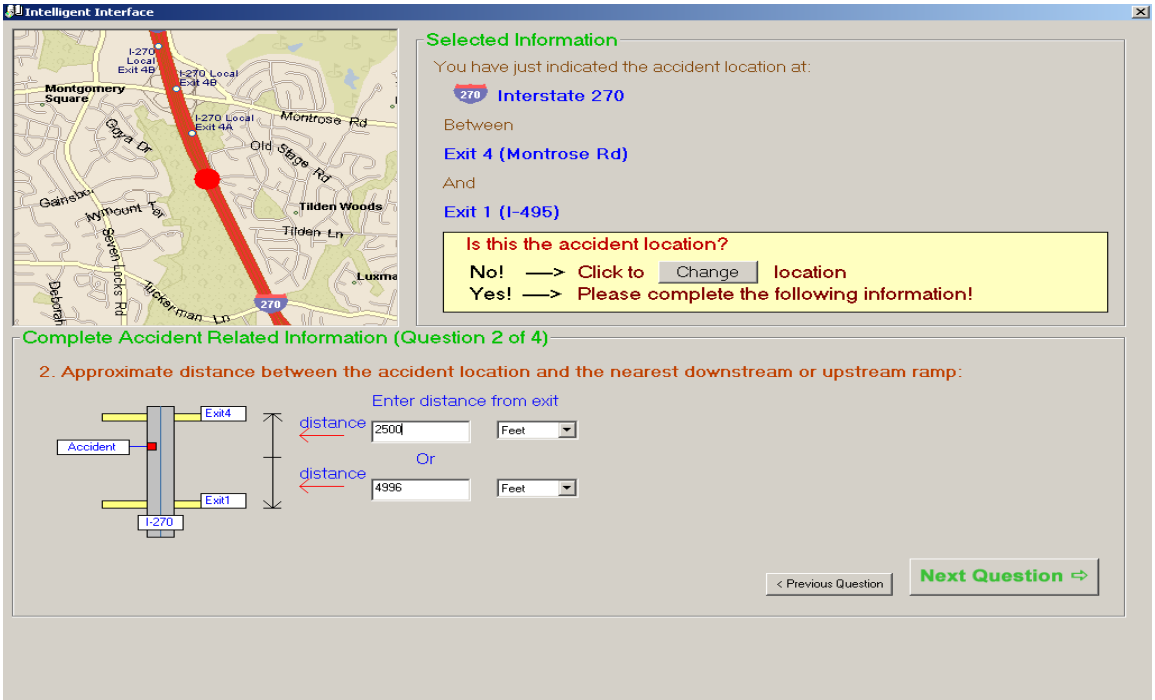

Figure 6-13: The interface for users to input precise location information

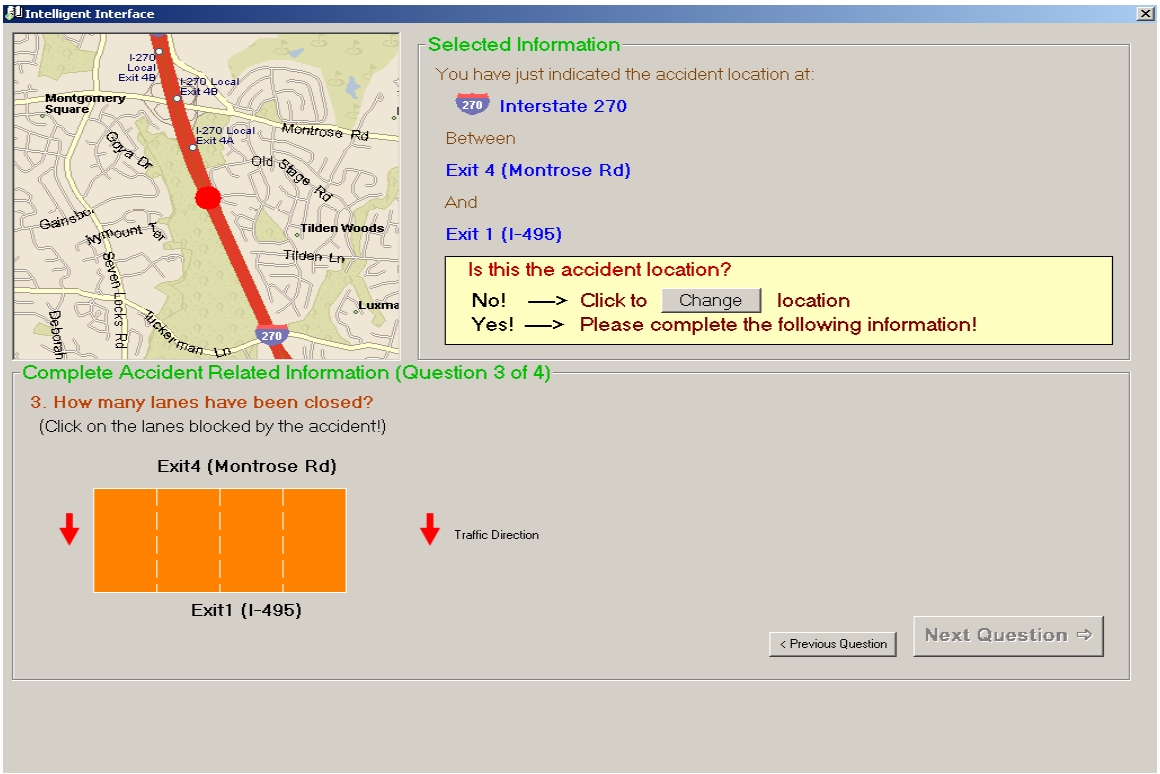

Figure 6-14:The interface for users to mark those blocked lanes

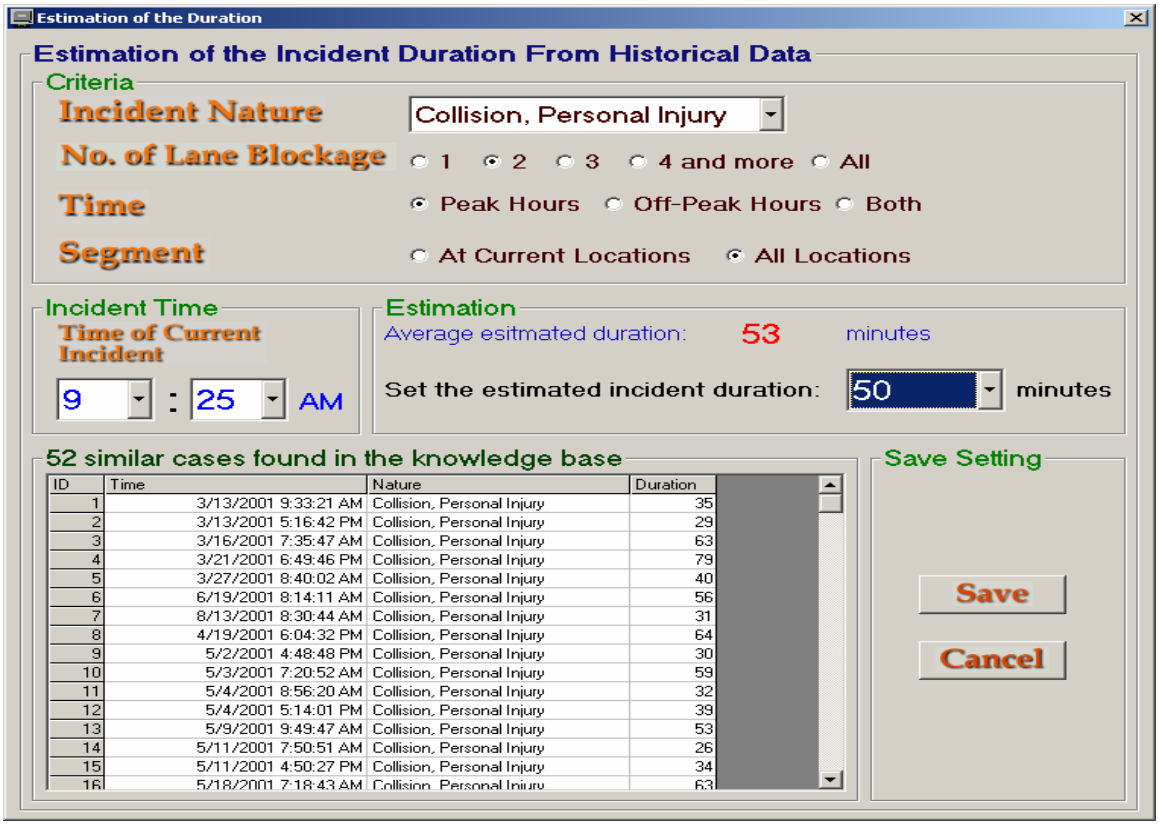

Figure 6-15: The interface for users to input the estimated incident duration

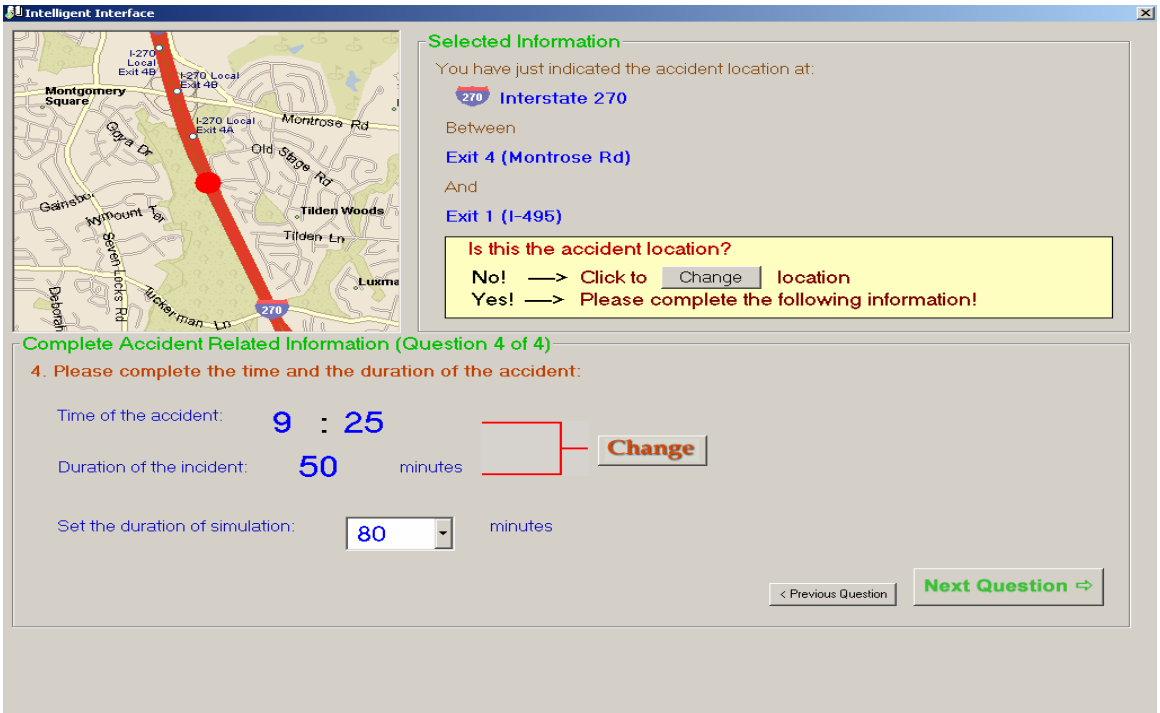

Figure 6-16: The interface for users to input the desired duration of simulation.

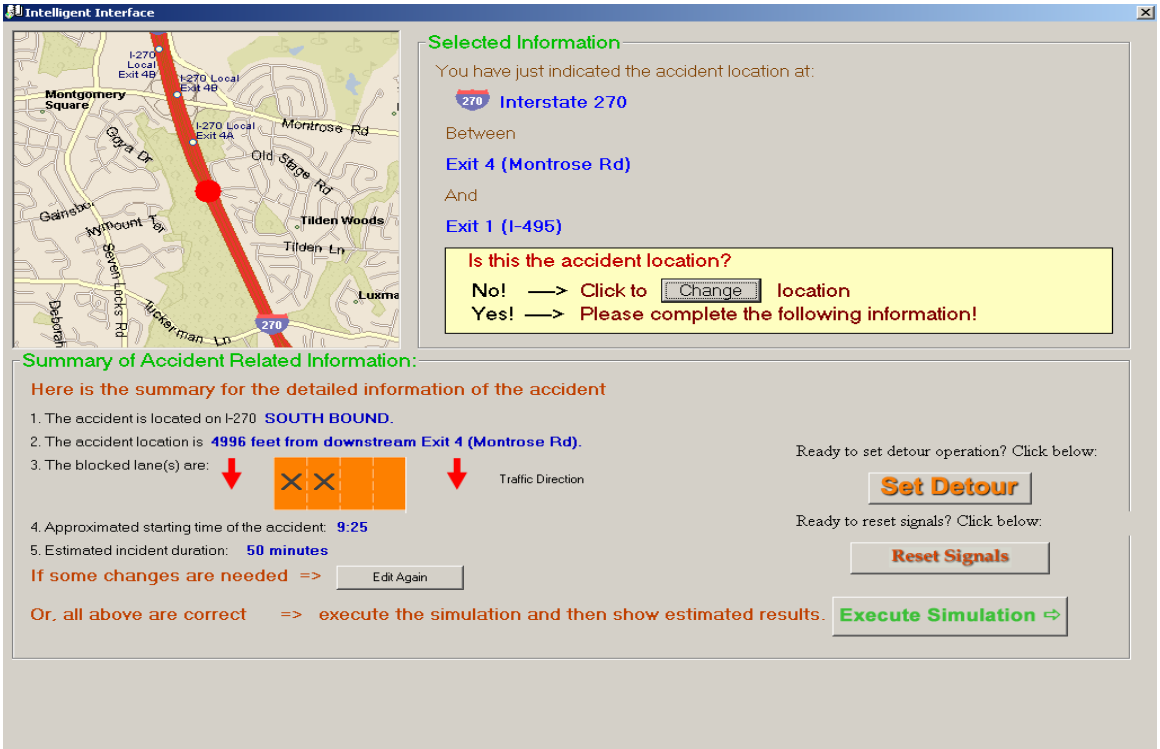

Figure 6-17: The interface for users to review the summarized incident information

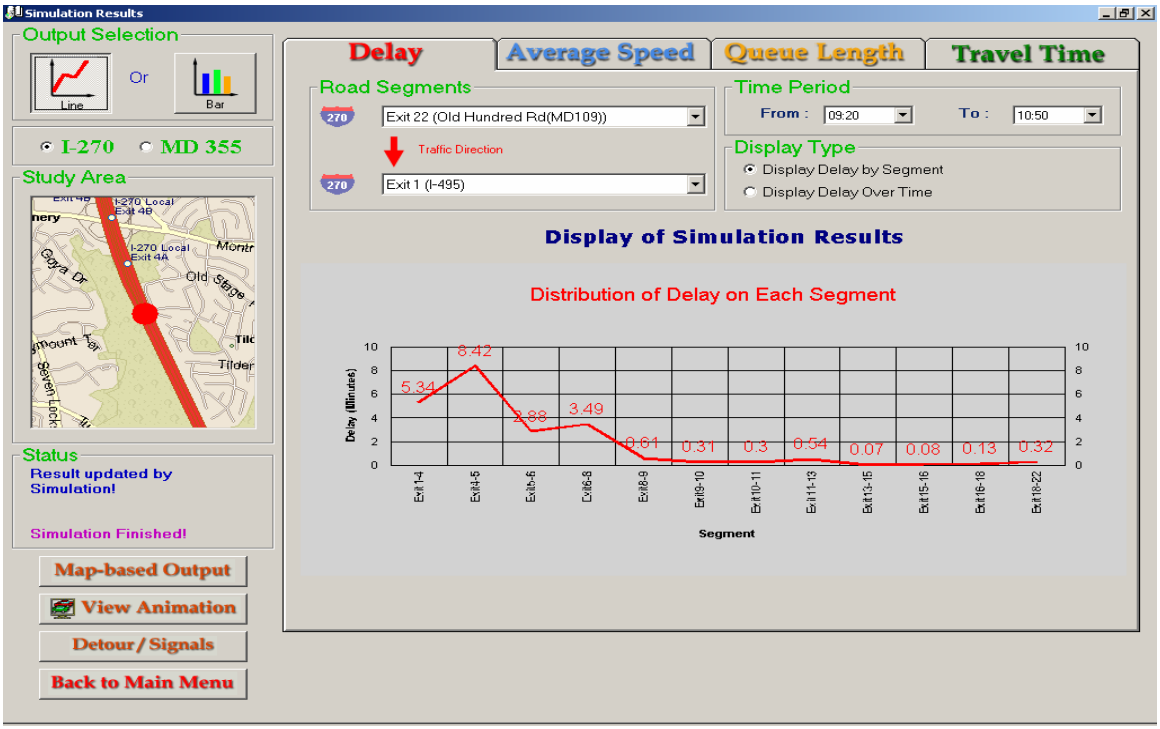

Figure 6-18: An example display of the chart-based output

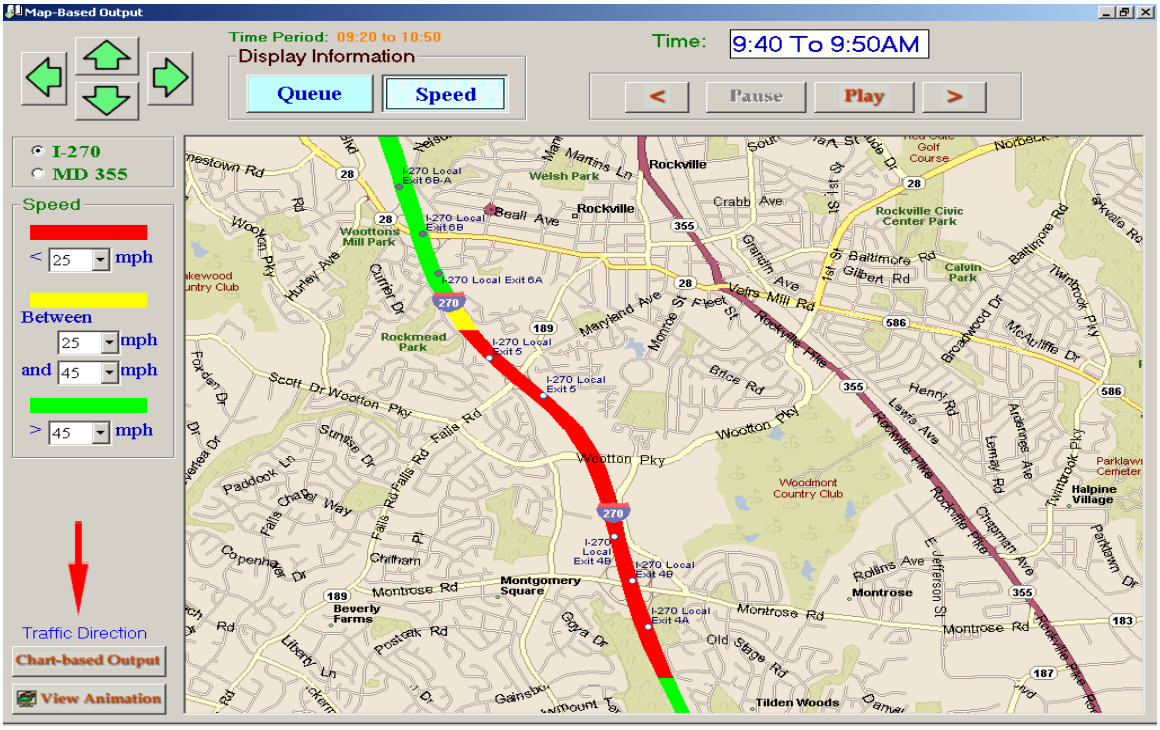

Figure 6-19: The map-based output of the average speed on I-270

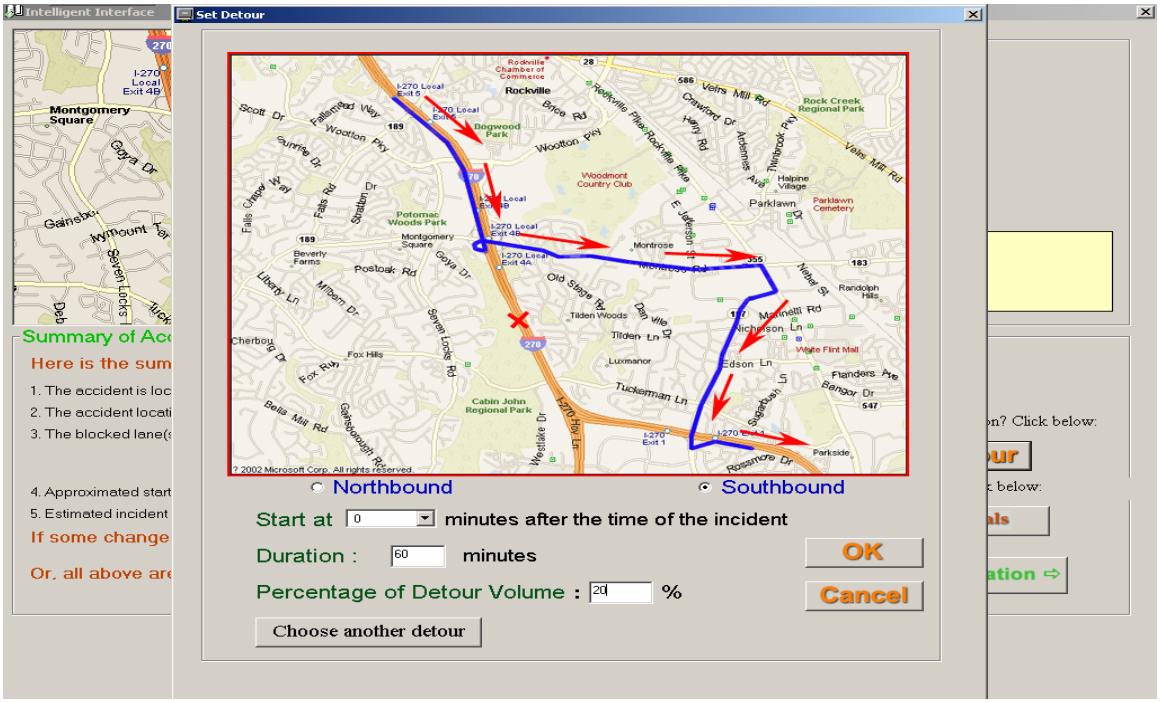

Figure 6-20: The input interface for the detour operation

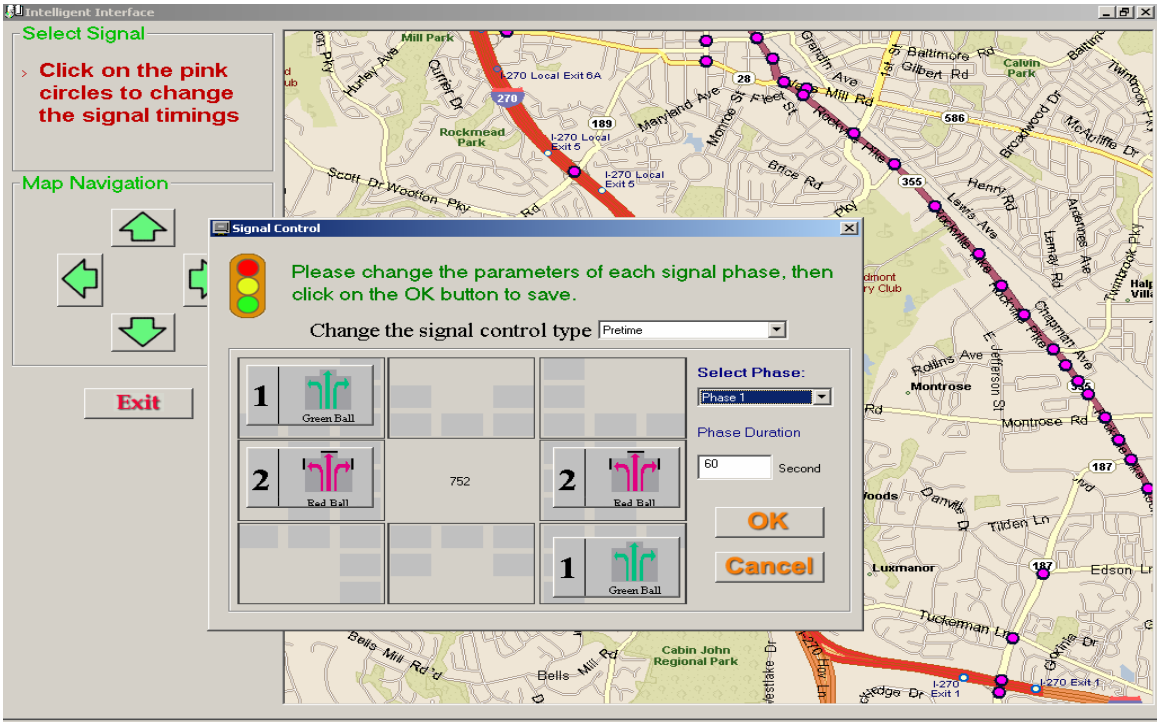

Figure 6-21:The interface for selecting the signals

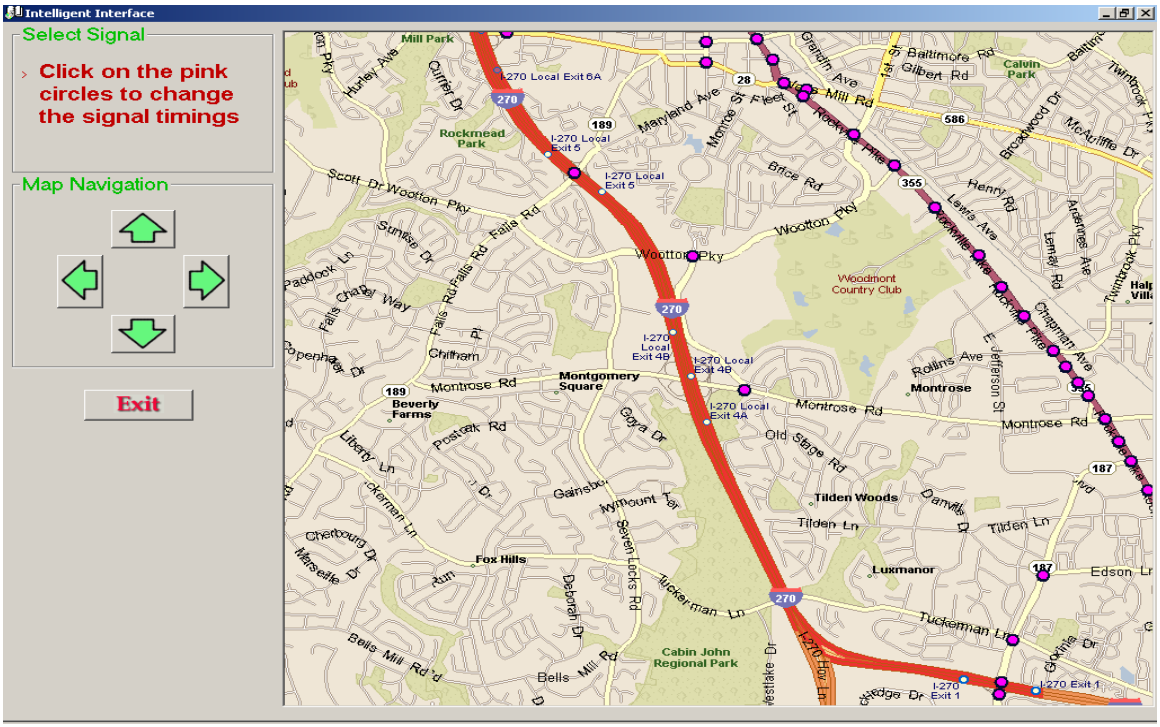

Figure 6-22: The interface for changing the signal timing

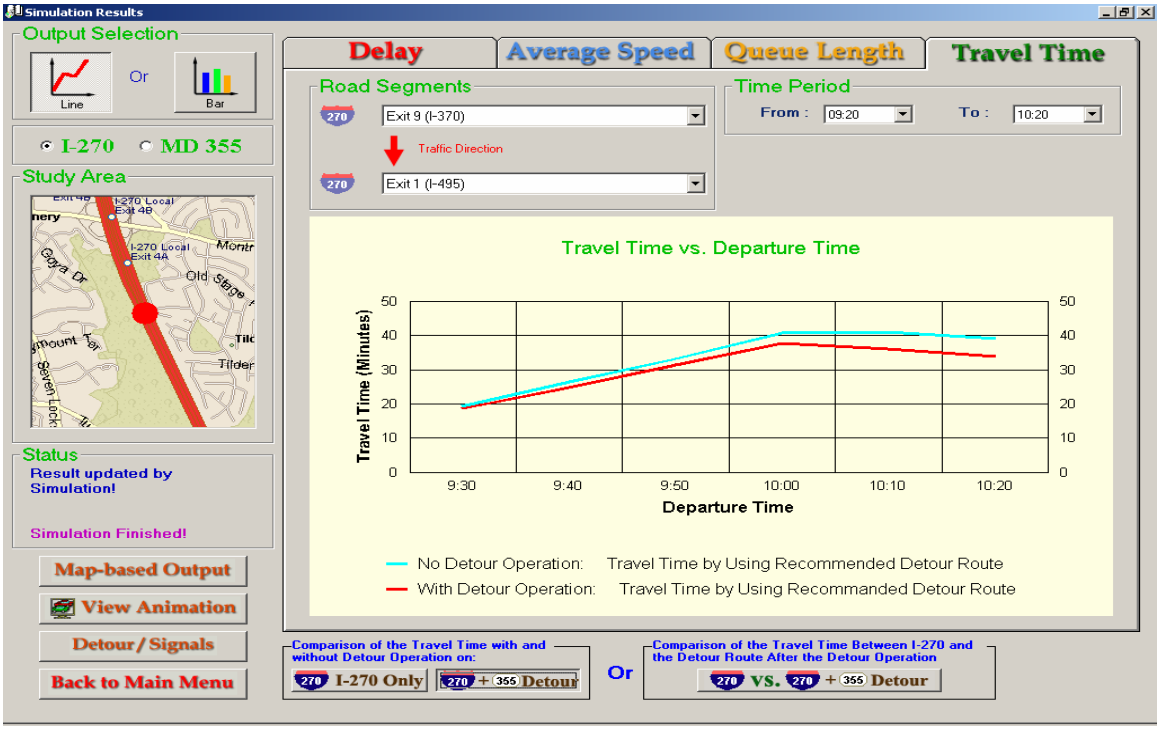

Figure 6-23: Comparison of the travel time vs. departure time via the detour route before and after the detour operation

6.3 Closure

This chapter has presented example applications of the Advanced application module for Traffic Management (ATM) that is designed to take full advantage of extensive information embedded in the database and power functions provided by the simulation module. The developed ATM offers a convenient and effective tool for traffic engineers to perform travel time estimation during recurrent day-to-day congestion, and project traffic impacts during incident response and management.

One may also use the ATM function to evaluate the effectiveness of candidate detouring plans during severe incidents, and select the optimal complementary control strategies such as ramp metering and signal re-settings. Through interactions with the module for estimating missing data, the ATM can be used for both on-line and off-line applications. Depending on the actual needs, one can expand the ATM functions for other applications such as emergency evacuation, or management of special events such as football games.

Chapter 7
Conclusions and Recommendations

7.1 Conclusions

This report has documented the developed Integrated Traffic Information and Simulation System (ITIS), including a detailed description of its principal components and their interrelations, the main functions embedded in each technical module, and key algorithms employed to verify users needs and to perform the required estimation. The proposed ITIS system offers an effective tool for MSHA engineers/planners to take full advantage of information available from on-line detectors, archive data, and simulation results for estimating travel times during non-recurrent and recurrent congestion patterns. With those embedded functions and customized interfaces, the ITIS system can also be used for work zone planning and operational analysis, and for assessment of various traffic control strategies.

The developed ITIS with its extensive information can also serve as an intelligent database system that can help potential users identify the data needs based on the requested applications, and perform the best estimation based on available data. Through the customized input and output graphical instructions, users of the ITIS can circumvent the complex process associated with applications of traffic simulation and advanced statistical models. More specifically, the developed ITIS has distinguished itself with the following key features:

- An intelligent interface for users to update all related information from either internet data transfer or manual input;
- An automatic assessment module to check the data needs for a requested application, identify available data, and suggest the necessary missing data estimation;
- A set of specially designed algorithms for estimating traffic volumes at those locations without detector stations based on the most recently updated information;

- A set of statistical models for performing a short-term prediction of traffic conditions (e. g, incident duration) on freeway segments;
- An automatic module that can construct the complex input dataset for the simulation analysis, based on the application proposed by the user;
- A customized graphical interface to guide users in step-by-step operations of the ITIS system and all embedded functions;
- A flexible supplemental module for the developed ITIS to interact with external computer programs or databases (e.g., CHART performance database), and perform advanced traffic management functions;
- A customized output for users to circumvent the need to comprehend the extensive but complex results from simulation, and directly perform the intended analysis; and
- An efficient mechanism for the ITIS to perform on-line simulation analysis, based on limited sensor data, archive information, and estimated results with embedded statistical algorithms.

In brief, the developed ITIS is an effective tool that combines the functions of GIS, simulation, and database. The system has been programmed for use in any window-based microcomputer, and will be designed for use with the Internet and web-based applications in the future research. The ITIS computer program at this stage is readily available for off-line planning and operational analyses, and shall be ready for on-line applications after all MSHA detectors have been evaluated and calibrated.

7.2 Recommendations

In developing the ITIS system, the research team has recognized that despite the lack of extensive sensor coverage on most freeways, there are a variety of data collected by different MSHA departments and stored with different computer software. Such information, if properly integrated, shall be sufficient for most planning and operational analyses performed by MSHA staff. In fact, to take advantage of such information and standardize the application methods are the primary purposes of this research project. Further development along this line should focus on the following tasks:

- Constructing the ITIS system for each major freeway corridor so that all associated information and routinely encountered issues as well as analysis methods can be documented and automatically updated in an integrated information system;
- Developing a decentralized operating center to coordinate all ITIS systems developed for major freeway corridors through a web-based information network;
- Design of a knowledge-based mechanism to document all major operational or planning activities as well as lessons in the ITIS, which can serve as the information-base to generate guidelines for similar applications and for training of new staff; and
- Continue the improvement of the ITIS computing software so that it can incorporate additional functions for analyses performed by MSHA staff, and interact more efficiently with its supplemental modules, especially for use in real –time applications.