IRISDS INTEGRATED REGIONAL INFORMATION SHARING AND DECISION SUPPORT

Integrated Corridor Management and Advanced Technologies for Florida

Final Report

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by the

Florida International University Lehman Center for Transportation Research

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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI* UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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16. Abstract

Integrated Corridor Management (ICM) strategies have been proposed to address needs and provide solutions beyond those that can be provided when applying advanced strategies and technologies to one transportation subsystem at a time. The goal of this project was to investigate ICM strategies for implementation in Florida and to demonstrate the applications of these strategies.

A Web-based system, referred to as Integrated Regional Information Sharing and Decision Support system (IRISDS), was developed to provide a platform to satisfy needs for ICM implementation, identified in this project. IRISDS receives information in real time from highway and transit agencies, communicates the information to the regional agencies, provides a platform for estimating and predicting the performance measures in real time, and utilizes the data to provide decision support to transportation agencies.

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Executive Summary

Integrated Corridor Management (ICM) can be defined as a collection of operational strategies and advanced technologies that allow transportation subsystems, managed by one or more transportation agencies, to operate in a coordinated and integrated manner, thereby increasing overall system throughput and enhancing the mobility, reliability, and safety for corridor users. ICM strategies have been proposed to address needs and provide solutions beyond existing strategies and technologies that are applied to one subsystem at a time.

The goal of this project was to investigate ICM for implementation in Florida and demonstrate the applications of these strategies. The specific objectives were:

- Review current state-of-the-art ICM strategies
- Identify ICM strategies as candidates for potential deployment on Florida corridors as part of this project
- Demonstrate selected ICM strategies for one or more corridors in Florida
- Test the performance of the selected and implemented ICM strategies
- Develop documentation of project task research efforts, results, and conclusions

The first task of this project is to review current state-of-the-art ICM strategies, with focus on the United States Department of Transportation (USDOT) ICM program activities. The intent is to form a baseline for identifying potential strategies for implementation. In correlation with this review, meetings were conducted with identified ICM partners in Miami-Dade County to understand their needs in relation to potential ICM solutions. These meetings were followed by a workshop attended by representatives from several transportation, law enforcement, and emergency management agencies in South Florida. It was concluded, based on the meetings with individual agencies and the workshop, that information sharing, transportation system performance measurement and prediction, and the development of decision support tools were the most important ICM applications that need to be implemented and demonstrated as part of

this project. It was also concluded that the I-95 corridor between the Golden Glades Interchange and SR-836, and the parallel segment of SR-7 in Miami-Dade County and associated transit lines, were to be used as a case study in the proof of concept of project developments.

A Web-based system, referred to as Integrated Regional Information Sharing and Decision Support system (IRISDS), was developed in this study to provide a platform to satisfy the identified needs. IRISDS receives and displays information in real time from highway and transit agencies, provides a platform for estimating and predicting performance measures in real time, and utilizes the data to provide decision support to transportation agencies.

IRISDS predicts and displays a number of measures to allow the assessment of incident impacts in real time. The measures include the percentage lane blockage, incident duration, traffic delay, and the potential for secondary incidents. The percentage of lane blockage is received in real time through the center-to-center Extensible Markup Language (XML) data stream from the Florida Department of Transportation (FDOT) SunGuide Traffic Management Center (TMC) in Miami, Florida. The values of the other measures are predicted in real time utilizing models based on the available information received through the XML Stream.

This study investigated the use of queuing theory and traffic simulation models, both microscopic and macroscopic, to predict incident delays as part of the real-time operations. Based on the results of this study, the methods investigated were able to accurately estimate traffic delays if the incident duration was accurately predicted and the drop in capacity accurately measured, and subsequently, these two parameters were inputted into the methods in real-time operation.

The study also developed and evaluated a method to estimate the diversion rates based on freeway mainline detectors without requiring measurements from on-ramp and off-ramp detectors. In addition, the study developed a module that utilizes bus Automatic Vehicle Location (AVL) data received in an XML data stream from the regional transit agency (Miami-Dade Transit in the investigated case) to estimate buses and general traffic travel times. These methods were also implemented as part of the developed IRISDS system.

Table of Contents

List of Figures

List of Tables

List of Selected Acronyms and Abbreviations

Acronyms and abbreviations used in the report are listed below.

ATIS	Advanced Traveler Information System
BRT	Bus Rapid Transit
CCTV	Closed Circuit Television Cameras
DMS	Dynamic Message Sign
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic Information System
HAR	Highway Advisory Radio
HCM	Highway Capacity Manual
HOV	High Occupancy Vehicle
ITS	Intelligent Transportation System
SIRV	Severe Incident Response Vehicle
STEWARD	Statewide Transportation Engineering Warehouse for Archived Regional Data
TMC	Traffic Management Center

1 Introduction

1.1 Background

Integrated Corridor Management (ICM) can be defined as a collection of operational strategies and advanced technologies that allow transportation subsystems managed by one or more transportation agencies to operate in a coordinated and integrated manner, thereby increasing overall system throughput and enhancing the mobility, reliability, and safety for corridor users. The transportation subsystems could include freeways, arterials, parking, public transit, and freight facilities.

ICM strategies have been proposed to address needs and provide solutions beyond existing strategies and technologies which are applied to one subsystem at a time. The United States Department of Transportation (USDOT) started the ICM Initiative in 2005 with the goal to manage a transportation corridor as a whole system and to optimize the use of the transportation resources across all modes of transportation within the corridor (*1*).

The Florida Department of Transportation (FDOT) has become a national leader in implementing advanced traffic management and traveler information systems, particularly in the area of limited access facilities. This investment included the development and implementation of a state-of-the-art SunGuide Transportation Management Center (TMC), advanced traffic management software, extensive detection and surveillance subsystems, advanced incident management programs, express lane/managed lane operations with dynamic pricing, traffic-responsive ramp metering, and advanced traveler information systems.

The FDOT has become cognizant of the need to operate transportation subsystems in an integrated and optimized manner. As a result, the FDOT established its Transportation System Management and Operations (TSM&O) Program, which is one of the most advanced programs of this type in the nation. The FDOT defines TSM&O as "an integrated program to optimize the performance of existing multimodal infrastructure through implementation of systems, services, and projects to preserve capacity and improve the security, safety, and reliability of our transportation system." The goals of the TSM&O include improving the communications, coordination, and collaboration among transportation partners, leading to a more effective use of existing infrastructure (*3*). ICM can be considered an effective tool to support the TSM&O objective in optimizing and coordinating subsystem operations for more effective leveraging of existing infrastructure. This research project is conducted to investigate and demonstrate ICM strategies for implementation in Florida.

1.2 Project Objectives

The goal of this project is to investigate ICM for implementation in Florida and demonstrating the applications of these strategies. The specific objectives are:

- Review current state-of-the-art ICM strategies
- Identify ICM strategies as candidates for potential deployment on Florida corridors as part of this project
- Demonstrate selected ICM strategies for one or more corridors in Florida
- Test the performance of the selected and implemented ICM strategies
- Document project task research efforts, results, and conclusions

1.3 Overview of Project Tasks and Document Organization

The first task of this project was to review current state-of-the-art ICM strategies, with focus on the USDOT ICM program activities. The intent is to form a baseline for identifying potential strategies for implementation. The results of this review are presented in Chapter 2 of this document. In correlation with the review mentioned above, meetings were conducted with identified ICM partners in Miami-Dade County to understand their needs in relation to potential ICM solutions. These partners include FDOT District 6, Miami-Dade Transit (MDT), Miami-Dade County Public Works Department (MDPW), Miami-Dade Expressway Authority (MDX), and FDOT District 4. These meetings were followed by a workshop attended by representatives from several transportation and law enforcement agencies in South Florida. It was concluded, based on the meetings with individual agencies and the workshop, that information sharing, transportation system performance measurement and visualization, and decision support tools are the most important ICM applications that need to be implemented and demonstrated as part of this project.

It was also concluded that the I-95 corridor between the Golden Glades Interchange and SR-836, and the parallel segment of SR-7 in Miami-Dade County and associated transit lines, are to be used as a case study in the proof of concept of project developments. The results of the meetings with ICM partners are also summarized in Chapter 2.

Based on the findings presented in Chapter 2, a Web-based system was developed for the proof-of-concept in this study to display regionally shared information in real time and to provide a platform for estimating and predicting performance measures in real time. This information is displayed to partner agencies and used in tools to support the decisions of transportation agencies. The functionality and high-level design of this system are presented in Chapter 3.

Chapter 4 and 5 discuss the details of the development and testing of decision support tools incorporated as part of the Web-based system mentioned above. The first tool predicts incident impacts on mobility and safety in real time and assigns an impact index based on the results. The second estimates diversion rates during incidents. The third utilizes Automatic Vehicle Location (AVL) data to estimate the travel time for both the bus service and general traffic.

1.4 References

1. USDOT's ICM Initiative Web site, **http://www.its.dot.gov/itsweb/icms/** index.htm, Accessed November 1, 2012.
2. Birriel, E. Transportation Systems Management & Operations TSM&O. Presentation made for the FDOT TSM&O Executive Board, November 16, 2011.
3. FDOT TSM&O Web site, **http://www.dot.state.fl.us/trafficoperations/TSMO/TSMO-home.shtm**, Accessed November 1, 2012.

2 Selection of ICM Strategies

2.1 Review of the National USDOT Program

The first task of this project was to review current state-of-the-art ICM strategies. The intent is to form a baseline for identifying strategies for potential implementations. In particular, a review was made of the extensive documentations produced by the United States Department of Transportation (USDOT) ICM program, including the concepts of operations and requirements of the eight pioneer sites of the ICM program. Based on the review, this study identified a set of generic ICM corridor needs and a set of operational strategies to satisfy these needs.

The results of the review were used as input in the discussions in meetings and a workshop with potential ICM partner agencies in Miami-Dade County, as described later in this chapter.

2.1.1 Overview of the USDOT ICM Program

The USDOT started the ICM Initiative in 2005 with the goal to manage and optimize the operations of a transportation corridor as a whole across all transportation modes and facilities within the corridor. The basic principle of the ICM initiative is that the management of individual transportation corridor components, such as modes and facilities, can be much more effective if accomplished in coordinated and integrated manners. ICM includes a set of procedures, processes, and information systems that support transportation systems managers in making proactive, coordinated decisions involving multimodal and multi-facility transportation systems (*1*).

ICM strategies can be classified into one of the following areas (*1*):

- Information sharing and coordination between agencies
- Improvement of operational efficiency based on coordinated operation
- Accommodation of cross-network route and modal shifts
- Promotion of cross-network shifts

The U.S. DOT chose eight pioneer sites in September 2006 for ICM development, deployment, and evaluation. These sites are: Montgomery County, Maryland; Minneapolis, Minnesota; Dallas, Texas; Houston, Texas; San Antonio, Texas; San Diego, California; Oakland, California; and Seattle, Washington. Phase 1 of the ICM program focused on reviewing existing corridor management practices and the development of initial technical guidance, such as a Generic Concept of Operations (ConOps) for ICM. An ICM ConOps document identified the intended ICM strategies for implementation, the potential benefits, and the stakeholders involved. Phase 2 developed analytic tools and methods that enable the implementation and evaluation of ICM strategies. Limited field testing was also included at select pioneer sites, evaluation of interfaces, and component operations of ICM. Phase 3 included the modeling, demonstration, and evaluation of ICM approaches that appear to offer the greatest potential. Phase 4 of the ICM project involved outreach and knowledge, and technology transfer.

2.1.2 Generic ICM Needs

One of the documents produced by the ICM program (*2*) reviewed the needs identified for each of the eight pioneer sites and summarized a set of generic ICM needs based on this review. The following is a summary of the identified high-level needs (*2*):

- Information sharing and coordination across different transportation systems
- Optimization of the supply and demand for transportation services within the corridor
- Decision support tools to assist in ICM implementation
- Information that affects traveler's route, mode, and travel time decisions
- Analysis and prediction of system performance for planning and real-time operations, including collection and processing of information in a timely manner, data archiving and analysis, estimation of demand, estimation of strategic behaviors of travelers such as willingness to shift, and performance measurement and prediction

2.1.3 Operational Strategies to Satisfy the ICM Needs

A number of ICM strategies have been proposed to satisfy the needs summarized in Section 2.1.2. According to USDOT documents, the ICM strategies can be organized into four categories:

- Information sharing and coordination between agencies
- Improvement of operational efficiency based on coordinated operation
- Promotion of cross-network shifts
- Planning for operations

The followings are examples of strategies that can be proposed under each of the four categories.

1. Information sharing and coordination. Examples of these strategies include:

   - Collection of real-time data for freeways, arterials, transit vehicles, and associated parking facilities
   - Supporting coordinated responses to reduce the impact of events, including sharing information between transportation system operators and public safety during emergencies and incidents
   - Construction and maintenance coordination and information sharing across all facilities and modes
   - Sharing information on transit services regarding incidents, service status, vehicle location, and transit schedules
   - Standard definition of actions for coordination

2. Improvement of operational efficiency based on coordinated operation. These strategies involve coordinated operation between freeways, managed lanes, arterial roadways, and transit facilities for optimal use of available capacity and accommodation of cross-network route and modal shifts, as in the examples below:

- Modifying arterial signal timing to accommodate traffic shifting from freeways
- Modifying ramp metering rates to accommodate traffic shifting from arterial roadways
- Modifying bus schedule to accommodate mode shift due to incidents
- Parking management to accommodate shift in demands
- Signal transit vehicles as priority if the vehicle is behind schedule
- Multimodal electronic payment of managed lane, transit, and parking
- Signal preemption and "best route" recommendation for emergency vehicles

3. Promotion of cross-network shifts. This capability will include:
    - Dissemination of information to allow selection of alternative routes, schedules, and modes of travel based on current or anticipated travel conditions
    - Promoting route shifts between roadways utilizing traveler information dissemination
    - Promoting modal shifts from roadways to transit utilizing traveler information dissemination
    - Promoting shifts between transit facilities utilizing traveler information dissemination
    - Re-routing buses around major incidents

4. Planning for operations. Examples of these strategies:
    - Data archiving and modeling
    - Planning coordinated incident management activities
    - Modeling and analysis of converting regular lanes to managed lanes
    - Analysis of optimized transit capacity in coordination with highway capacity during recurrent congestion, incidents, and special events
    - Analysis of lane use control (reversible lanes/contra-flow)
    - Coordinating scheduled maintenance and construction activities between agencies
    - Bus-on-shoulder lane or congestion bypass modeling and analysis

2.2 Identification of Regional Needs

In correlation with the review mentioned above, meetings were conducted with identified ICM partners in Miami-Dade County to understand their needs and discuss potential ICM solutions to be assessed and implemented in this project. These partners included FDOT District 6, Miami-Dade Transit (MDT), Miami-Dade County Public Works Department (MDPW), Miami-Dade Expressway Authority (MDX), and FDOT District 4. These meetings were followed by a workshop attended by representatives from several transportation and law enforcement agencies in South Florida. In the meetings and workshop, technologies and strategies were discussed for potential assessment as part of the project. In addition, a corridor was selected to be used as a case study for this assessment, as discussed in the following subsections.

2.2.1 Project Stakeholders

The identified stakeholders of the selected I-95 corridor are listed below.

- FDOT District 6
- FDOT District 4
- Florida Turnpike Enterprise (FTE)
- Miami-Dade Transit (MDT)
- FDOT Central Office
- Miami-Dade Expressway Authority (MDX)
- Traffic Signals & Signs Division of Miami-Dade County Public Works Department (MDPW)
- Law enforcement agencies (Florida Highway Patrol and local police)
- County and local fire agencies (Miami-Dade Fire)
- Construction and maintenance departments of FDOT, county, and cities
- Florida 511 traveler information service
- South Florida Regional Transportation Authority (SFRTA)

2.2.2 Regional Needs

Initial interviews with FDOT, MDT, MDX, and MDPW indicate that these stakeholders consider the following non-prioritized list as important needs for the region:

- Information and video sharing
- Decision support tools for integrated multi-facility (freeways and arterials) and multimode (highway and transit) operations
- Multimodal, multi-facility traveler information system and effective dissemination of information to promote route, mode, and time shifts
- Transportation system performance measurements and visualization (multi-facility and multimodal)
- Coordinated incident management (multi-agency, multi-facility and multimodal)
- Transit signal priority
  - MDPW selects a central architecture for bus priority.
  - MDPW needs detailed information to optimize bus priority, including schedule/status, immediate left-turn/right-turn movement information, number of passengers, and schedule status. There is an issue with the latency of the current wireless communication system to the buses. MDPW requires one-second data on bus locations. MDT currently can only provide information at 6-7 second updates, and it is difficult to provide less than 3-second data due to the current communication capacity.
- Instrumentation of arterial streets with sensors and travel time measurements on these streets
  - Tests are currently conducted by FDOT District 6 of automatic vehicle identification (AVI) technologies from different vendors, such as Bluetooth-based technologies and data purchased from a private sector provider (INRIX).
- Emergency vehicle support
  - It is advantageous to have emergency vehicle routing based on real-time information.

    - Signal preemption for emergency vehicles: MDPW currently implements a central architecture of preemption. For optimal operations, MDPW desires exact locations of emergency vehicles and the mode of operation (such as emergency status, special conditions, etc.).
- Park and ride management and information
- Construction and maintenance coordination
    - Currently, cross-agency information sharing regarding construction and maintenance is not adequate.
    - Coordination of construction agency schedules is needed between agencies and alternative routes.
- Coordination of traffic signal operations with other facilities and modes
    - Improving arterial signal timing by providing information about events and freeway incidents.
    - Questions remained regarding the best method to adjust timing in case of events: Manual based on information provided, traffic responsive from plan library, or traffic adaptive.
- Transit adjustment of bus operations during events and highway incidents
- Park and ride information for travelers

The meeting minutes for the interviews with the MDT, MDX, and MDPW is located in Appendix A. The needs identified in these meetings were later confirmed and expanded in the stakeholder workshop. Following the workshop, additional meetings with the abovementioned agencies and the Florida Highway Patrol Troop E were conducted to confirm the results of the workshop. Arrangements were made to obtain real-time data from these agencies to support the development of this project.

2.2.3 Selected ICM Strategies for Demonstration

Based on the meetings with individual agencies and the workshop, the most important ICM applications that need to be implemented and demonstrated as part of this project included: multimodal, multi-facility information sharing; transportation system performance measurement, prediction, and visualization; and decision support tools that use information from different sources to support coordinated operations.

Based on the findings above and further discussions with FDOT project management, a proof-of-concept Web-based system was developed to display regionally shared information in real time and provide a platform for estimating and predicting performance measures, displaying the predicted information to partner agencies, and ultimately using this information in tools to support the decisions of transportation agencies.

2.2.4 Selected Corridor for Demonstration

Based on discussions with the agencies, it was also concluded that I-95 (including general use lanes and managed lanes) paralleled by NW 7th Avenue and NW 27th Avenue, combined with existing/planned transit facilities, was a good case study for the project. Figure 2-1 shows a map of the selected I-95 corridor. However, because of the unavailability of MDT bus automatic vehicle location (AVL) data for this corridor (due to the planned update for this corridor), Kendall Drive was also selected for use as a corridor to demonstrate the use of AVL data from the Kendall Drive bus service (referred to as Kendall Cruiser).

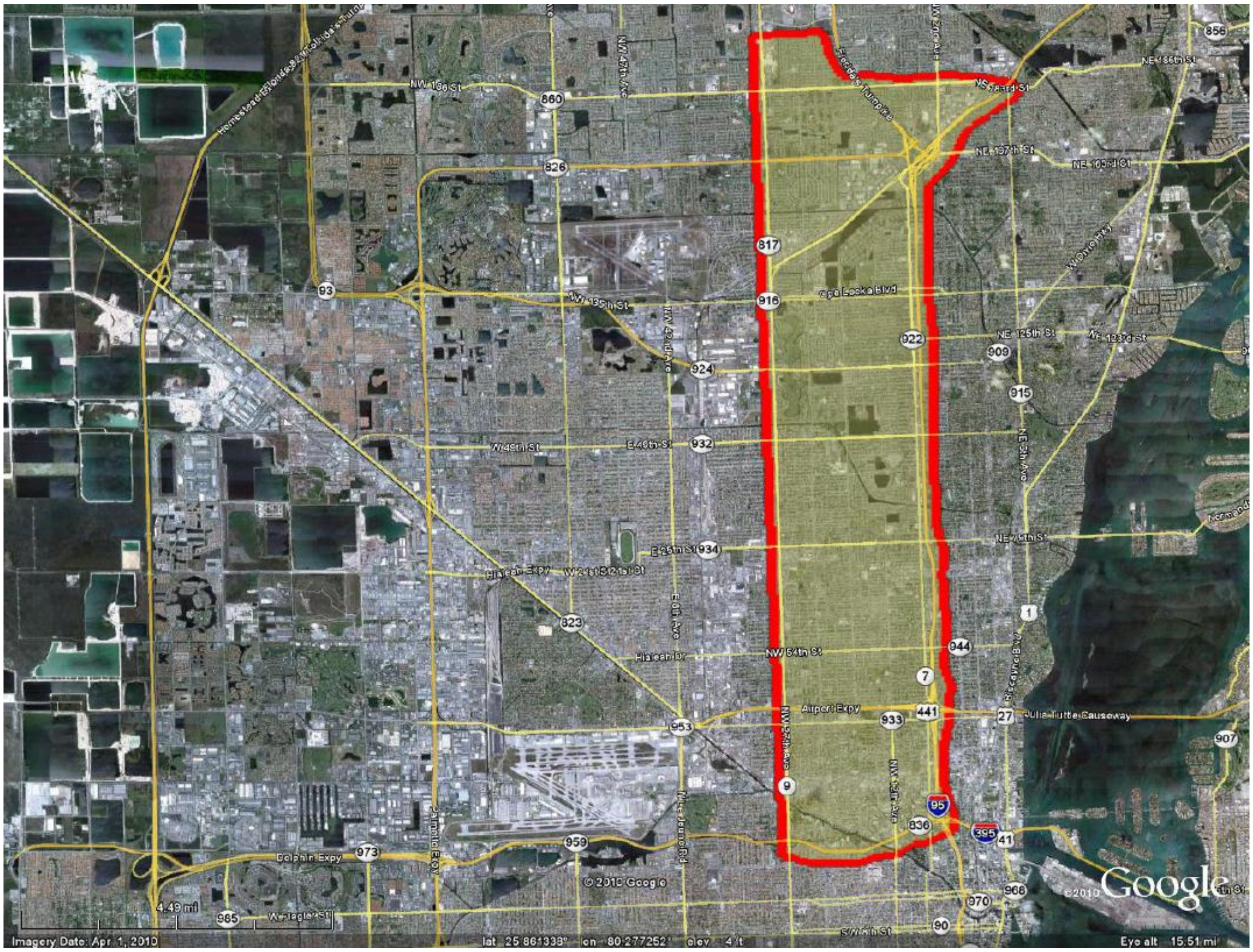


Figure 2-1 Selected I-95 Corridor

2.2.5 Relationship to Statewide Intelligent Transportation System (ITS) Architecture

The development of a regional information sharing and decision support system is expected to support a number of service packages of the National ITS Architecture (*3*) and Florida Statewide ITS Architecture (SITSA) (*4*), including:

- Regional Traffic Control
- Incident Management
- Multimodal Coordination
- Traveler Information Systems

- Regional Parking Management Systems
- Maintenance and Construction Activity Coordination

Figure 2-2 to Figure 2-6 show visualizations of the related service packages (formerly referred to as market packages) from the Southeast Florida regional ITS architecture, which is part of the Florida statewide architecture. These service packages confirm the need for information sharing and coordinated management of regional transportation facilities, identified earlier in this chapter.

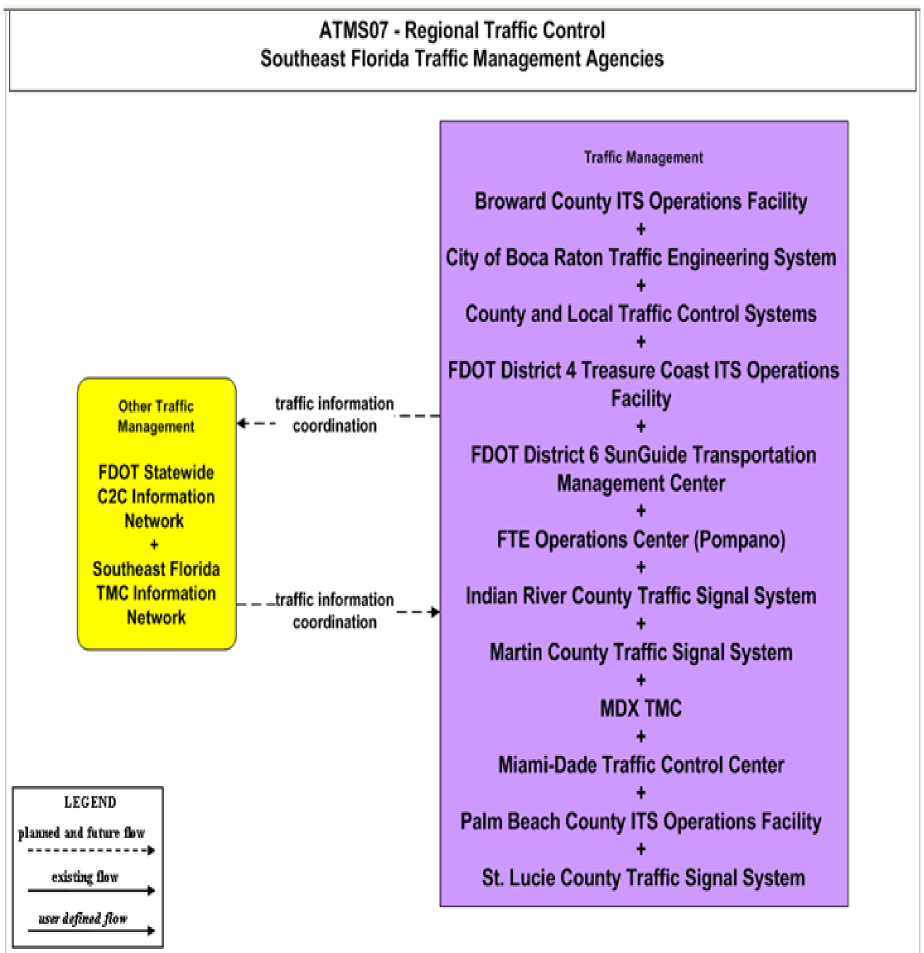


Figure 2-2 Regional Traffic Control Service Package

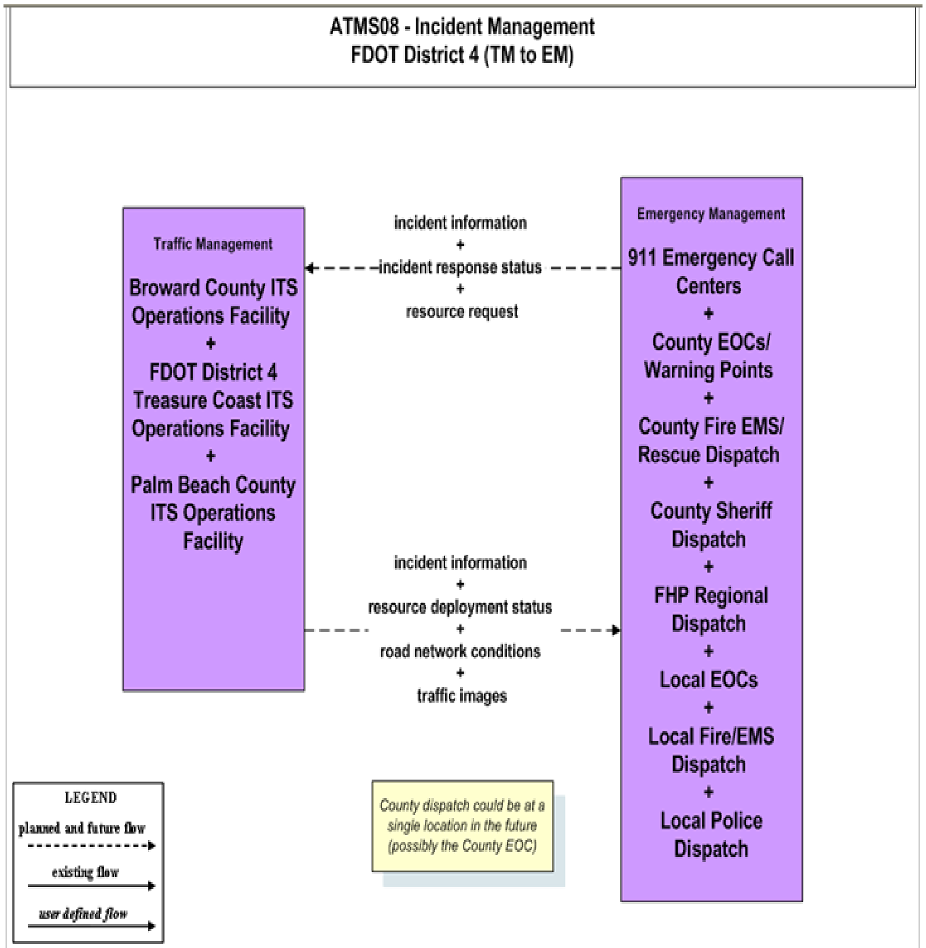


Figure 2-3 Incident Management Service Package

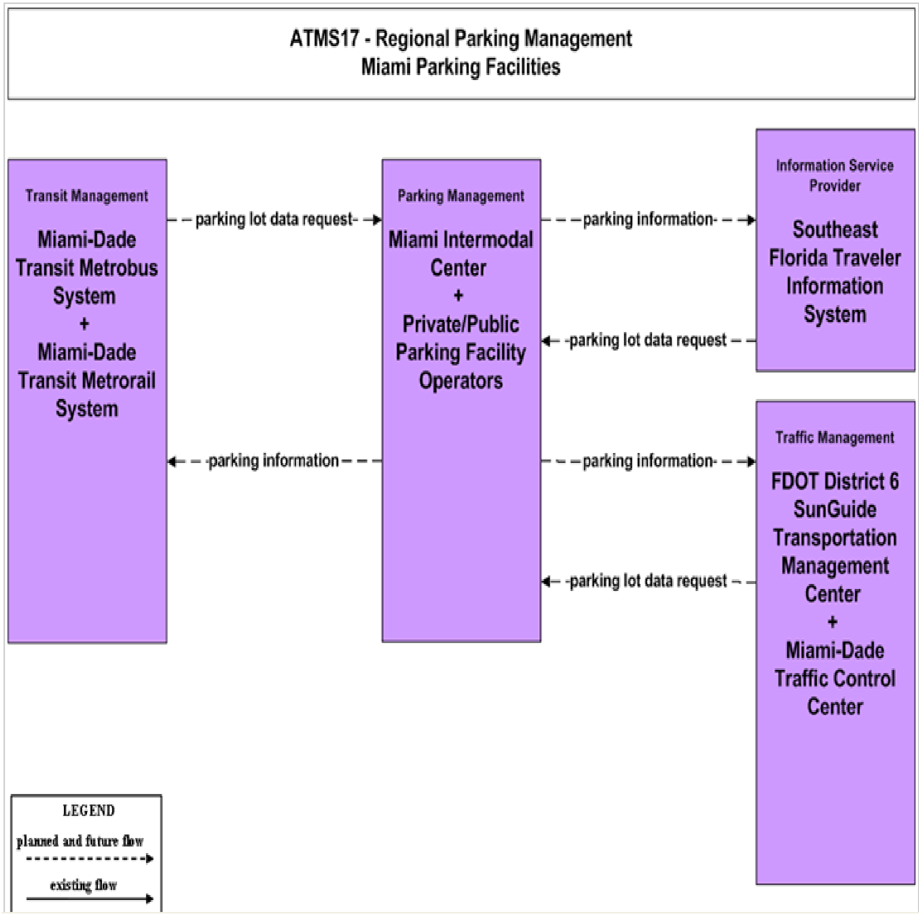


Figure 2-4 Regional Parking Management Service Package

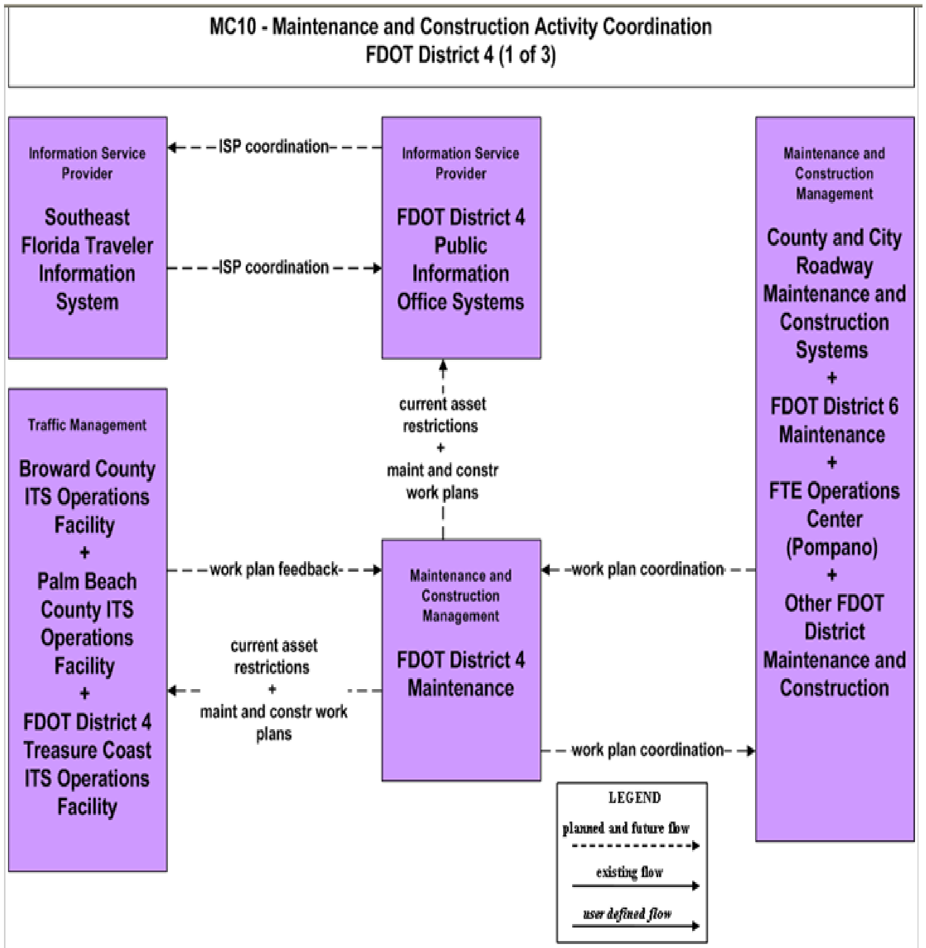


Figure 2-5 Maintenance and Construction Activity Coordination Service Package

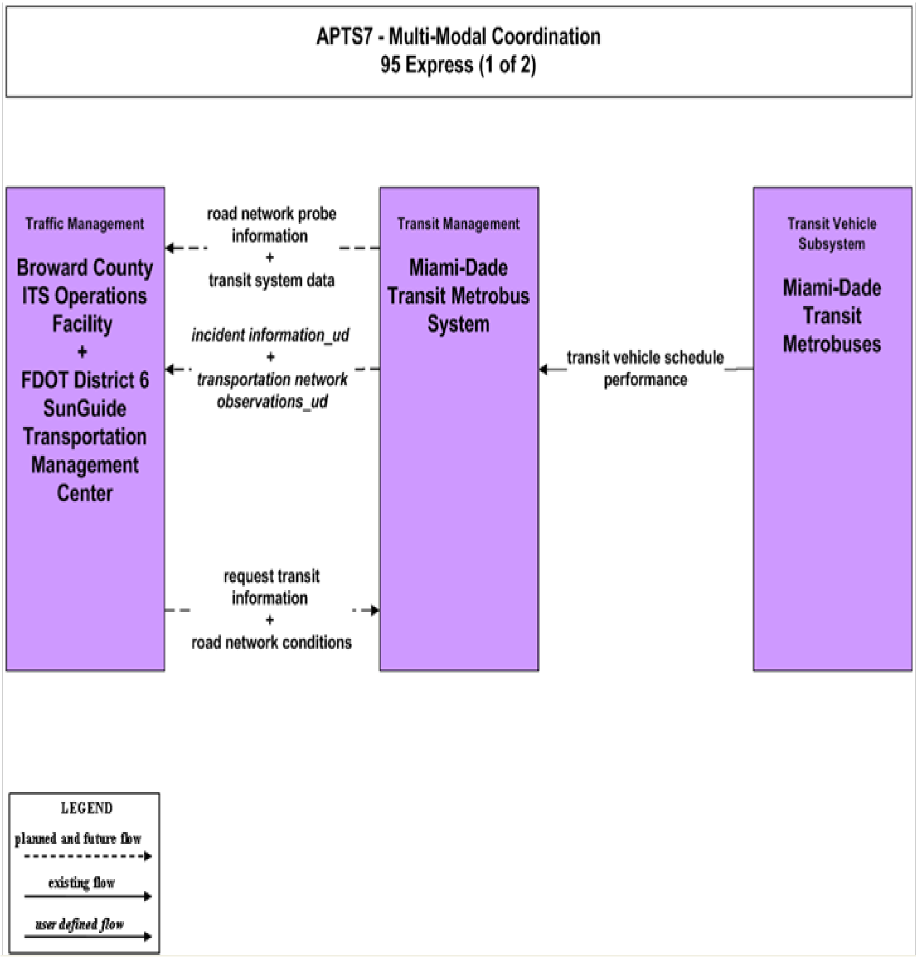


Figure 2-6 Multimodal Coordination Service Package

2.3 References

1. Cronin, B. Integrated Corridor Management (ICM). Presented at the 16th ITS World Congress, Stockholm, Sweden, 2009.
2. Hill, C., and J.L. Kaiser. Integrated Corridor Management (ICM) Initiative ICMS Surveillance and Detection Requirements for Arterial and Transit Networks. Prepared for the USDOT by Mixon/Hill, November 2008.
3. The National ITS Architecture, **http://www.iteris.com/itsarch/**, Accessed October 15, 2012.
4. Florida Department of Transportation, **http://www.dot.state.fl.us/trafficoperations/ITS/Projects_Arch/SITSA.shtm**, Accessed October 15, 2012.

3 Real-Time Information Sharing

This section includes an overview of the functionalities and design of the Web-based system developed in this study based on the needs identified in Chapter 2. Important needs identified for ICM operations in Chapter 2 include information sharing and coordination across different transportation systems and agencies, decision support tools to assist in agency operation, and the analysis and prediction of system performance for planning and real-time operations. A Web-based system, referred to as Integrated Regional Information Sharing and Decision Support system (IRISDS), was developed in this study to provide a platform to satisfy these needs. IRISDS receives real-time information from highway and transit agencies and utilizes the data, in some cases combined with archived data, to provide decision support for estimating and predicting system performance using data mining techniques and traffic analysis, as well as simulation modeling.

3.1 High Level Architecture

Figure 3-1 shows the high-level architecture of IRISDS utilizing the standard three-tier architecture model. The bottom tier is the data tier, which includes a central database that receives and stores data from multiple remote sources as needed. The central database serves as a data hub that integrates and "normalizes" data from different data sources to homogenous data formats that are used by the application. In order to facilitate the application development, the central database used in this project was developed using the Oracle relational database system. Although there are many modern relational database systems available, such as the Microsoft SQL Server and MySQL (free software), Oracle is chosen since the SunGuide system has utilized the Oracle database. Thus, utilizing the Oracle database minimizes the efforts needed to clean up and transform the data.

The presentation layer was designed to facilitate the operations of end users and to display information in useful and easy to understand formats. The presentation layer provides a Web-based graphical user interface, which permits the users to view shared information and performance measures, as well as recommendations from the implemented decision support tools. The Microsoft Visual Studio.Net environment was chosen as the major application development environment, and the webpages were written using ASP.Net.

The business logic tier, which serves as an intermediary between the presentation and the data layers, retrieves and modifies data from the presentation and data layers, and performs detailed processing of the collected data. The functions can be divided into two levels: sharing and displaying performance measures to allow managers to make informed decisions based on the measures, and providing decision-support tools to aid the manager in the decision-making process. At the performance measures sharing level, traffic data (speed, volume, and occupancy), travel time, incident information, Dynamic Message Signs (DMS) messages, and other information for the corridors managed by different agencies are shared in nearly real-time among different agencies. Based on this information, the decision support component provides algorithms and methods that can be applied to provide predictions of the performance and possible solutions in case of incident, emergency, special events, and construction conditions.

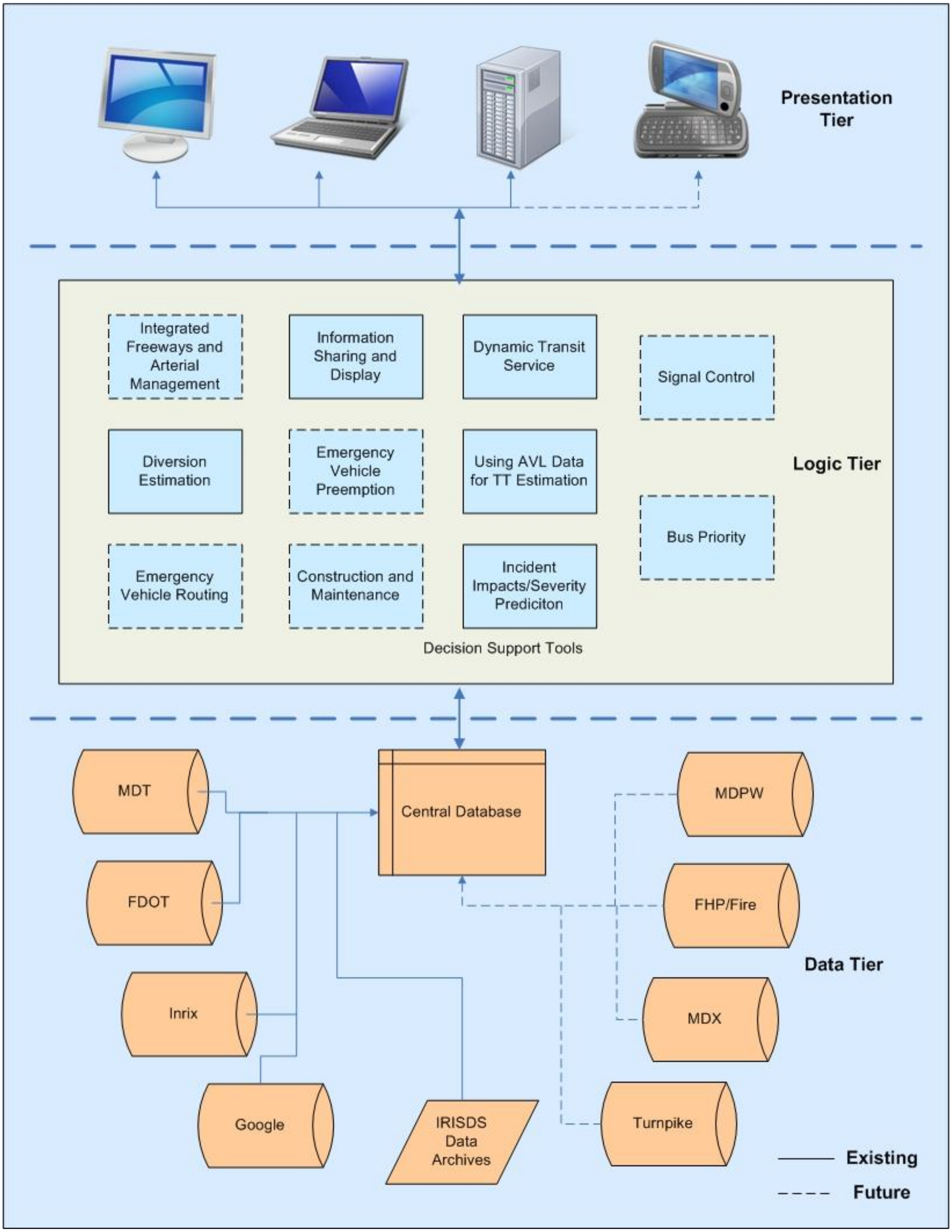


Figure 3-1 The System Architecture for the ICM Project

3.2 Data Tier

As stated earlier, one of the most important functionalities of IRISDS is regional information sharing. The types of information to be shared can be identified by examining the architecture flows in the regional ITS market packages, as well as additional information from further discussions with the regional transportation agencies. Ideally, the information sharing should be done by IRISDS receiving center-to-center (C2C) messages in XML format according to ITS standards. However, in some cases, information sent through other means, such as FTP sites, e-mail, or through virtual private network (VPN) access to agency databases, may be used. The shared information in the current state of implementation is discussed below.

3.2.1 FDOT SunGuide Traffic and Incident Management Information

This information is received through C2C messages, according to the FDOT specifications of the SunGuide C2C Interface Control Document (ICD) (*1*). An important component of the SunGuide deployment is a common C2C data format so that information can be exchanged between centers operated by different agencies. The SunGuide C2C data could be "status" data (informational) or it could be "control" data. Only informational data are relevant to current IRISDS deployment. The data deposited by the SunGuide software into the C2C infrastructure was converted to an ITS-standard message format. In order to deploy the C2C infrastructure, it is necessary to have TCP/IP connectivity between the agencies wanting to utilize the C2C functionality. The C2C infrastructure is implemented using Web Services, so any network appliances must be configured to allow the HTTP communication.

The FDOT C2C infrastructure provides the following status information: roadway network, locale data (roadway and location inventory), current traffic condition data (including speed, occupancy, volume), events messages (incidents, closures, weather alerts), floodgate messages, traveler information messages, status of field devices (DMS, closed circuit television (CCTV) cameras, environmental sensors, HAR, and roadside DSRC transceivers), and probe vehicle data.

It should be recognized that the shared detector data in the C2C stream are aggregated at the 20-second aggregation levels. In addition, only a subset of incident information is included in the data stream. Thus, if more detailed information is required, shared network folders or file transfers (between SunGuide agencies and IRISDS) may be needed.

At the present stage of the implementation, only SunGuide data from FDOT District 6 is received by IRISDS. However, in the future, data from other regional agencies can be received. For example, in Southeast Florida, data from Miami-Dade Expressway (MDX), Florida Turnpike, and FDOT District 4’s Broward and Palm Beach TMCs can be received, allowing a regional information sharing environment between these agencies.

3.2.2 Miami-Dade Transit (MDT) Information

Discussions with the MDT Information Technology Department were conducted to identify the best method for communicating MDT bus information to IRISDS. Two options were discussed and considered, as follows:

- In Option 1, information sharing with MDT is established by utilizing a Web Service to publish the data from the MDT database (similar to the SunGuide C2C infrastructure mentioned above). With this option, MDT would host a web service application in one of their servers to read data from the MDT database. The data is then published through a web server. Applications such as IRISDS would subscribe to this web service by making an HTTP request, and the real-time data would be communicated to IRISDS.
- In Option 2, shared network folders or ftp is used. This option is easier, but is a less reliable solution.

In this project, Option 1 was selected, and a web service was established for communicating MDT data to IRISDS. The Automatic Vehicle Location (AVL) data of MDT buses is captured utilizing an XML feed web link. Because the MDT AVL system was being updated, only buses running the Kendall Cruiser (Route 288) were received. This route currently only runs during weekday rush hours.

An example of the XML feed is shown in Figure 3-2. It provides the following bus information:

- Bus name
- Current time
- Current GPS location of bus (latitude and longitude)
- Bus speed
- Bus direction
- Route name
- Route direction
- Service day


```
<GPS>
- <Bus>
    <BusName>09517</BusName>
    <BusTimeStamp>1/24/2012 3:52:35 PM</BusTimeStamp>
    <Latitude>25.69145</Latitude>
    <Longitude>-80.45393</Longitude>
    <BusSpeed>026</BusSpeed>
    <BusDirection>W</BusDirection>
    <curRoute>288-PM</curRoute>
    <curDirection>West bound</curDirection>
    <curService>WEEKDAY</curService>
  </Bus>
- <Bus>
    <BusName>09518</BusName>
    <BusTimeStamp>1/24/2012 3:52:55 PM</BusTimeStamp>
    <Latitude>25.68656</Latitude>
    <Longitude>-80.3822</Longitude>
    <BusSpeed>017</BusSpeed>
    <BusDirection>W</BusDirection>
    <curRoute>288-PM</curRoute>
    <curDirection>West bound</curDirection>
    <curService>WEEKDAY</curService>
  </Bus>
- <Bus>
    <BusName>09519</BusName>
    <BusTimeStamp>1/24/2012 3:52:35 PM</BusTimeStamp>
    <Latitude>25.69091</Latitude>
    <Longitude>-80.30603</Longitude>
    <BusSpeed>011</BusSpeed>
    <BusDirection>SW</BusDirection>
    <curRoute>288-PM</curRoute>
    <curDirection>West bound</curDirection>
    <curService>WEEKDAY</curService>
  </Bus>
</GPS>
```


Figure 3-2 An Example of the XML Feed for the MDT Bus AVL Data

3.2.3 MDPW Signal System Data

The third important source of data for the regional data sharing system is arterial traffic data from MDPW, which includes both signal control plans and real-time signal timings, in addition to detector measurements. In this project, a workstation is deployed at the MDPW and connected to the MDPW network. It allows remote access through the VPN account, as shown in Figure 3-3. Signal operation definition and timing report can be downloaded by using such connection. However, due to security constraints, it was not possible to import the data in real time to feed the IRISDS application. Further discussion with MDPW indicated that an XML data stream should be used to communicate the data from the MDPW system to IRISDS. However, this is not possible without a modification of the MDPW system to allow sending such data feeds. The system provider estimated that this would cost about $50,000, which was beyond the scope of this project.

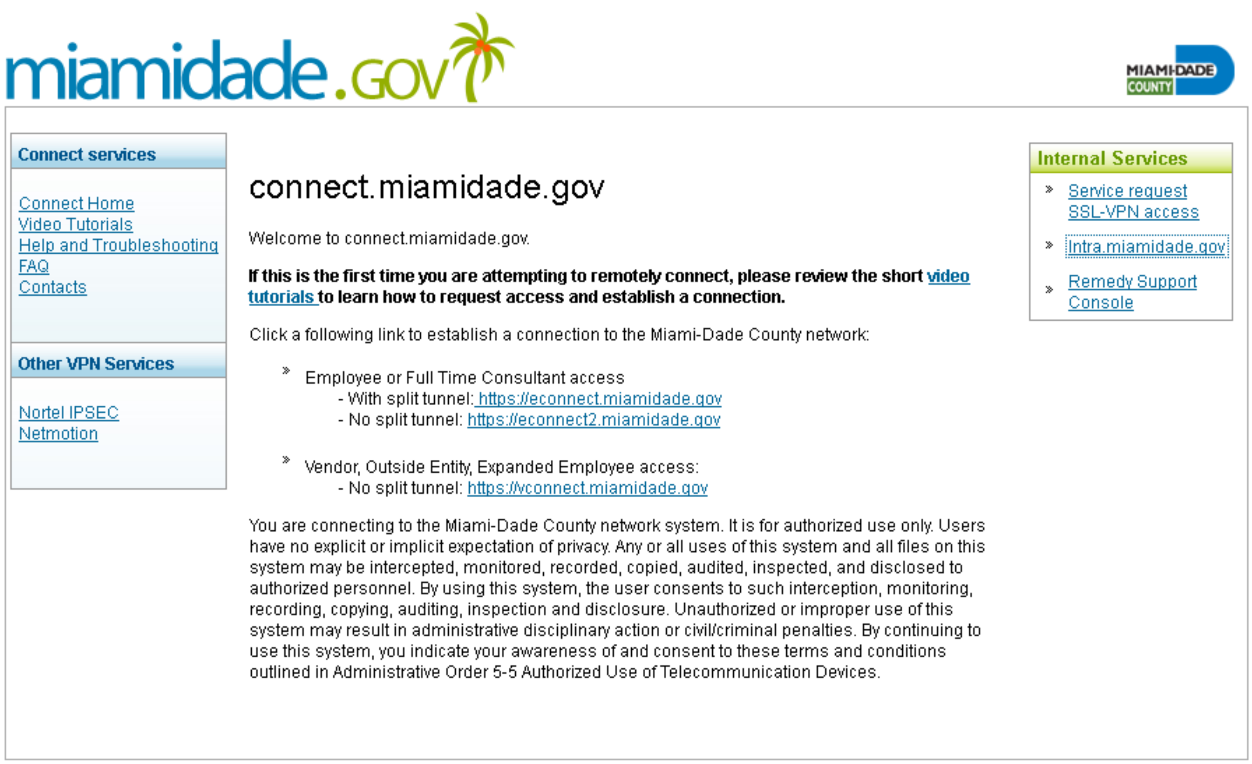


Figure 3-3 Access Interface for MDPW Signal System Data

3.2.4 INRIX Data

INRIX is another source of real-time travel time data that is used by IRISDS. INRIX is a private sector provider of real-time data. This private sector data provider utilizes what is sometimes referred to as crowd sourcing of GPS probe data, in which data from multiple sources are collected and fused to provide travel time estimates that are then distributed to public and private sector users. INRIX utilizes sophisticated statistical analysis to estimate travel time based on the data collected from multiple sources, including commercial fleet, delivery, and taxi vehicles, as well as consumer cellular GPS-based devices, including the iPhone, Android phones, and Ford SYNC. Real-time data feed from INRIX is retrieved by IRISDS via a HTTP Web Services application programming interface (API). Before using this API, a member agency should sign a Data Use Agreement with the University of Maryland to get a vendor ID and a consumer ID. For real-time access to the Inrix Data, a GetSecurityToken API call should first be made by a service requestor to obtain a renewable security token for authentication purposes. An example of a GetSecurityToken API call using HTTP is given below:

http://na.api.inrix.com/V3/Traffic/Inrix.ashx?action=getsecuritytoken&vendorid=176656765&consumerid=5df78ed9-3413-49fc-be73-fe1a3f3453d

The XML response to this API call contains the security token and the server path required by the subsequent API calls. Figure 3-4 shows an example of the XML response.


```
- <Inrix docType="GetSecurityToken" copyright="Copyright INRIX Inc." versionNumber="4.3"
  createdDate="2012-11-21T21:40:13Z" statusId="0" statusText="" responseId="68e6586f-0851-453c-
  95a7-2a47ebc6312e">
  - <AuthResponse>
      <AuthToken expiry="2012-11-21T22:39:00Z">4IdE54RKHXESG73HNFST-
      WdEz3BUBuy88jRbnBJ2f8I|</AuthToken>
      <ServerPath>devzone.inrix.com/traffic/inrix.ashx</ServerPath>
    - <ServerPaths>
        <ServerPath type="API" region="NA">http://na.api.inrix.com/V3/Traffic/Inrix.ashx</ServerPath>
      </ServerPaths>
    </AuthResponse>
  </Inrix>
```


Figure 3-4 An Example of the XML Response to GetSecurityToken API Call

After the security token and the server path are provided by the XML response, another API GetRoadSpeedInSet can be called to request the traffic data. There are five types of traffic data: speed, travel time, data confidence score, average speed, and reference speed. An example of GetRoadSpeedInSet API to request all the five types of traffic data is given below:

http://na.api.inrix.com/V3/Traffic/Inrix.ashx?Action=GetRoadSpeedInSet&TmcSetId=234767890&SpeedOutputFields=Speed,Average,Reference,Score,TTM&Units=0&FullTMC=true&Token=WdEz3BUBuy88jRbnBJ2f8I|

The XML response to a GetRoadSpeedInSet API call provides the requested traffic data; an example of this XML response is shown in Figure 3-5.


```
- <Inrix docType="GetRoadSpeedInSet" copyright="Copyright INRIX Inc." versionNumber="3.0.0"
  createdDate="2010-06-21T23:33:38Z" statusId="0" statusText=""
  responseId="9b555mjhfd4399-4930-8ce4-ca3d59972153">
  - <RoadSpeedResultSet coverage="255">
    - <RoadSpeedResults timestamp="2010-06-21T23:33:37Z">
        <TMC code="125P05037" speed="58" average="65" reference="65" delta="-7" score="30"
        c-value="83" travelTimeMinutes="0.351"/>
        <TMC code="125-05102" speed="65" average="68" reference="65" delta="-3" score="30"
        c-value="100" travelTimeMinutes="5.634"/>
        <TMC code="125N05068" speed="63" average="65" reference="65" delta="-2" score="30"
        c-value="100" travelTimeMinutes="0.439"/>
        <TMC code="110+04271" speed="23" average="17" reference="63" delta="6" score="30"
        c-value="100" travelTimeMinutes="2.159"/>
        <TMC code="110-04640" speed="59" average="62" reference="64" delta="-3" score="30"
        c-value="100" travelTimeMinutes="2.405"/>
        <TMC code="125N05254" speed="65" average="65" reference="65" delta="0" score="20"
        c-value="" travelTimeMinutes="0.392"/>
      </RoadSpeedResults>
    </RoadSpeedResultSet>
  - <InputParameters>
      <InputParameter name="action" value="getroadspeedinset"/>
      <InputParameter name="tmcsetid" value="1000022"/>
      <InputParameter name="token" value="r-
      wRdIMUf7drePHdjksj56klliikFNcG3KKwDtWWL-0|"/>
    </InputParameters>
</Inrix>
```


Figure 3-5 An Example of the XML Response to GetRoadSpeedInSet API Call

3.2.5 Other Information for Future Sharing

IRISDS was developed as a proof of concept system for data sharing. The following information will be considered for future sharing:

- Information about the availability of parking spaces at major park and ride facilities in the corridor.
- Construction and maintenance from various agencies, including information about maintenance and construction schedules, damaged infrastructure, planned road closures, and construction from the agencies responsible for operating the affected facilities.
- Special events details including estimated number of attendants.
- County signal system data.
- Traffic operation data from other FDOT districts and toll authorities.
- Information from emergency and law enforcement agencies.

3.2.6 Data Archiving

Data archiving in IRISDS stores information needed to support the performance prediction and decision support tools in the "Business Tier." At the present time, two data types are archived to provide this support:

- MDT AVL data: This data is needed to develop a model to provide estimates of travel times on arterials.
- Traffic detector data: This data is archived to allow the displaying of traffic conditions in the time that has passed since the beginning of the incident when a user of IRISDS requests the display of incident impacts.

3.3 Business Logic Tier

As stated earlier, the business logic tier in IRSIDS allows the provision for a number of functions that can be categorized as information sharing, performance prediction, pattern recognition, and other decision support tools. A discussion of the business tier modules that has been implemented in this project is presented or provided below.

3.3.1 Information Sharing

The purpose of information sharing in the developed system is to allow managers to make informed decisions based on real-time information (and if needed, historical information) collected from multiple agencies. Currently, IRISDS mainly shares information through webpage displays. These displays will be described in the Presentation Tier. In the future, however, if specific applications require, IRISDS will communicate information to partner agencies' software, as needed, using XML data streams.

The shared information through IRISDS includes:

- Events
- Camera status
- DMS messages
- Traffic information
- Inrix data
- Transit data
- Google traffic information

3.3.2 Prediction of Incident Impacts

IRISDS provides a number of measures to allow the assessment of incident impacts in real time. The measures include the percentage lane blockage, incident duration, traffic delay, and the potential for secondary incidents. The percentage of lane blockage is received in real time through the XML stream from the FDOT SunGuide TMC in Miami, Florida. The values of the other measures are predicted in real-time utilizing models, based on the available information received through the XML Stream.

IRISDS incorporates a module for real-time prediction of incident impacts, including the prediction of incident duration, the potential for secondary incidents, and the traffic delays due to incidents. Three methods have been investigated for use in predicting incident delays, including queuing theory, macroscopic simulation based on highway capacity manual procedures, and a microscopic simulation model. The queuing theory and microscopic simulation analyses are currently implemented in IRISDS, and the macroscopic simulation method will be implemented in the future. The details of the implementation and investigation are included in Chapter 4.

3.3.3 Assignment of Incident Impact Index

IRISDS assigns an incident impact index to each incident based on the predicted incident impacts discussed in the previous section. The impact severity index is calculated using an algorithm that accounts for incident attributes and impacts, including lane blockage, incident duration, average incident delay, queue length, and the potential for secondary incidents. This index is estimated based on the opinions of TMC operations' managers, who regard the severities of these incidents as a function of their attributes. The impacts and attributes of real-world incident cases were presented to TMC operations' managers. The managers were asked to select a severity level for each incident case. The classification algorithm utilizes this selection as a basis for assigning severity levels to newly detected incidents in real time. The description of the impact severity assignment is presented in Chapter 4.

3.3.4 Estimation of Diversion Levels

IRISDS also includes a module to estimate the diversion rates based on freeway mainline detectors, without requiring measurements from on-ramp and off-ramp detectors. To estimate the average diversion rate for a given corridor, the methodology of this study utilized a set of incidents that are extracted from the incident database. The attributes of the selected incidents were then associated with measurements from traffic detector stations at locations upstream and downstream of the incident locations. This association allowed the determination of the diversion rates based on detector measurements. This was done, as described in Chapter 5, by calculating the difference between the average cumulative traffic volumes of typical no-incident days and the cumulative volumes for the incident day based on mainline traffic detector measurements.

3.3.5 Travel Time based on Transit AVL Data

As an additional proof of concept that information gathered from one agency can be used to support other agency operations, the AVL data collected from the MDT Kendall Cruiser service is used to estimate the travel time for both the bus service and general traffic. The general traffic travel times is calculated by subtracting the bus delays at bus stop influence areas, and by utilizing additional adjustments to account for differences in bus and passenger car operations outside the influence areas, as quantified by travel time studies. Both real-time and historical travel time estimations can be made. The real-time travel time differential between current day and historical operations can be examined to detect abnormal congestion levels. This module is discussed in more details in Chapter 6.

3.4 Presentation Tier

In general, the presentation tier of IRISDS uses Web-based displays that include maps, tables, and dashboards. These displays are designed to provide the user interface required for the business tier. The two main pages in the Presentation Tier are the Information Sharing and Decision Support Tools. The following subsections present a description of these displays.

3.4.1 Information Sharing Displays

Figure 3-6 illustrates the main information sharing interface in the IRISDS. As shown in this figure, the user has the option to select various data layers to be visualized on the map. These layers include: Events, Camera status, DMS message, Traffic info, INRIX, Transit, and Google traffic.

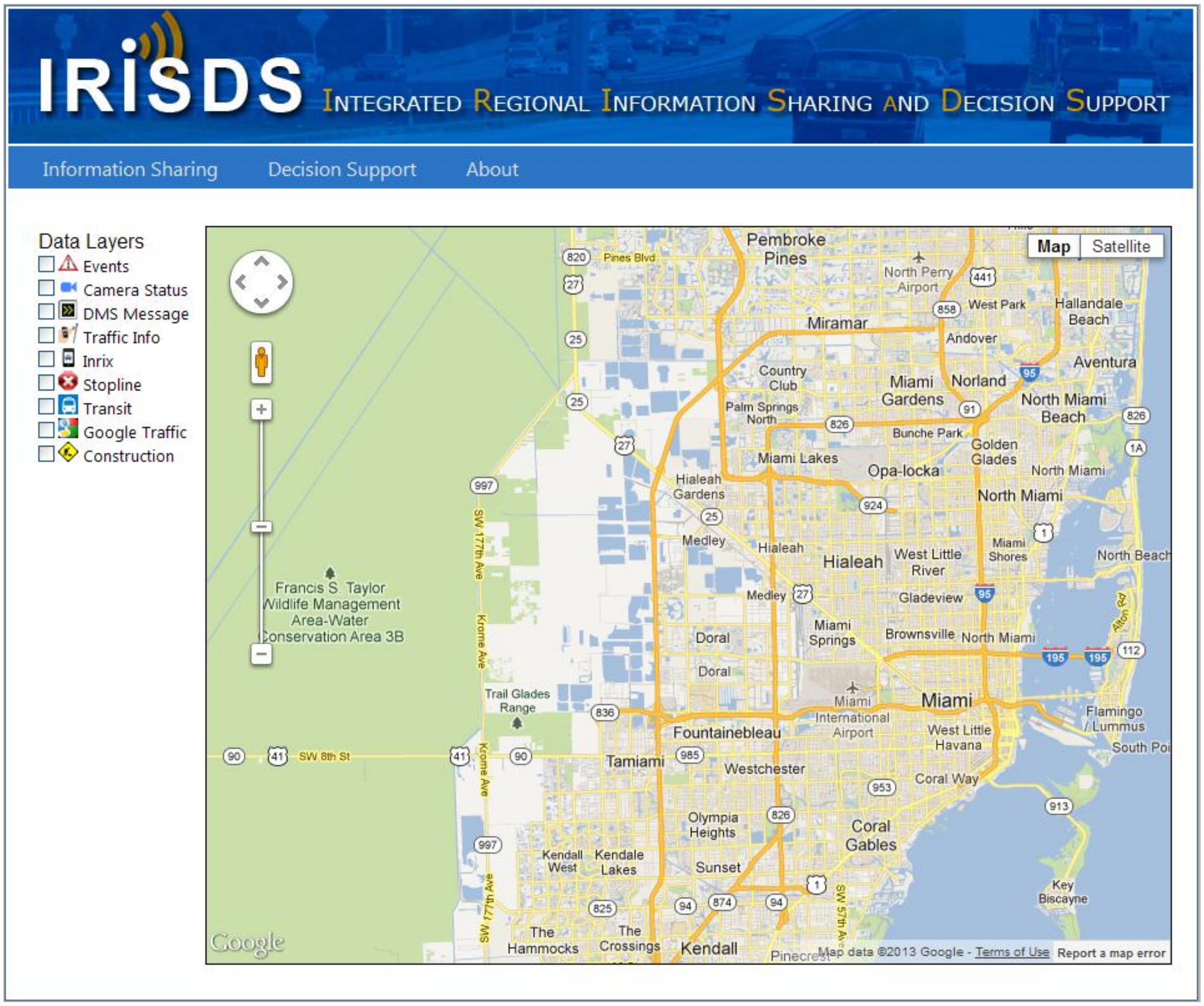


Figure 3-6 IRISDS Information Sharing Interface

Figure 3-7 shows a snapshot of the Events data layer interface. Once this data layer is checked, the event icons show up in the map to indicate the locations of the events. Left-clicking an event icon will generate a callout window containing the detailed event information, which includes:

- Name of TMC
- Event ID
- Start time of the event
- Severity of the event
- Status of the event
- Type of the event

- Road condition
- Weather condition
- ATIS severity
- Update time

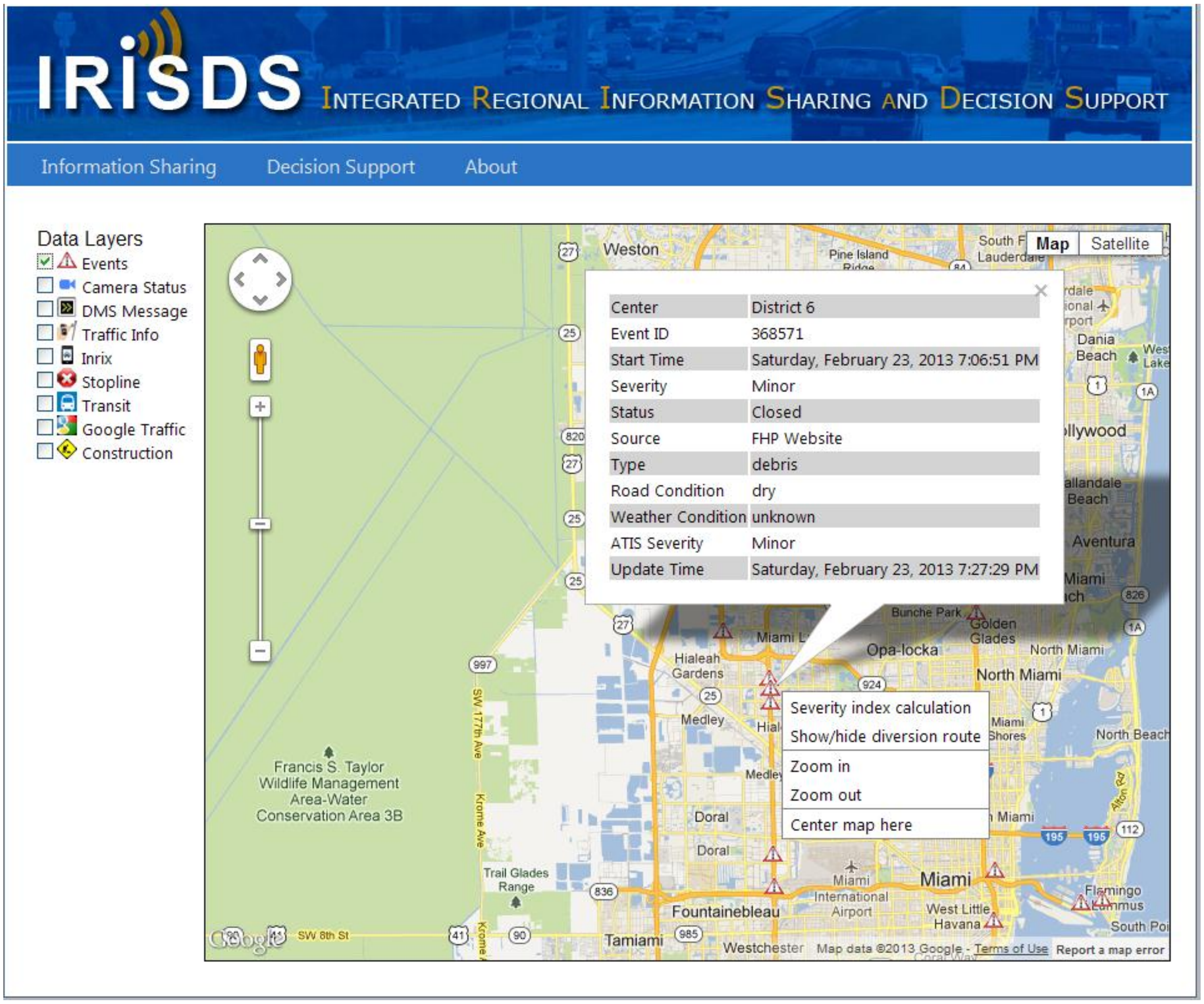


Figure 3-7 Data Layers – Events

Right-clicking an event icon generates a menu with the following menu items:

- Severity index calculation (based on the method developed in this study as described in Chapter 4)
- Show/hide diversion route
- Zoom in

- Zoon out
- Center map here

Clicking the Severity Index Calculation menu item produces a pop-up window, as shown in Figure 3-8. Detailed event information and predicted incident impacts, including predicted duration, queue length, average diversion rate, and severity index are displayed in this window. The incident impacts are predicted as described in Chapters 4 and 5. The traffic conditions during the event are also presented in both a chart and time-space contour plots. The prediction of incident impacts on mobility is done using queuing theory equations. However, it is also possible to predict these impacts using simulation analysis, if a simulation model is available for the corridor under investigation. By clicking the Simulate button, the user can start the simulation process, and the simulation results will be shown under the Simulate button, which can be compared with the real-world results, and also show the predicted traffic conditions.

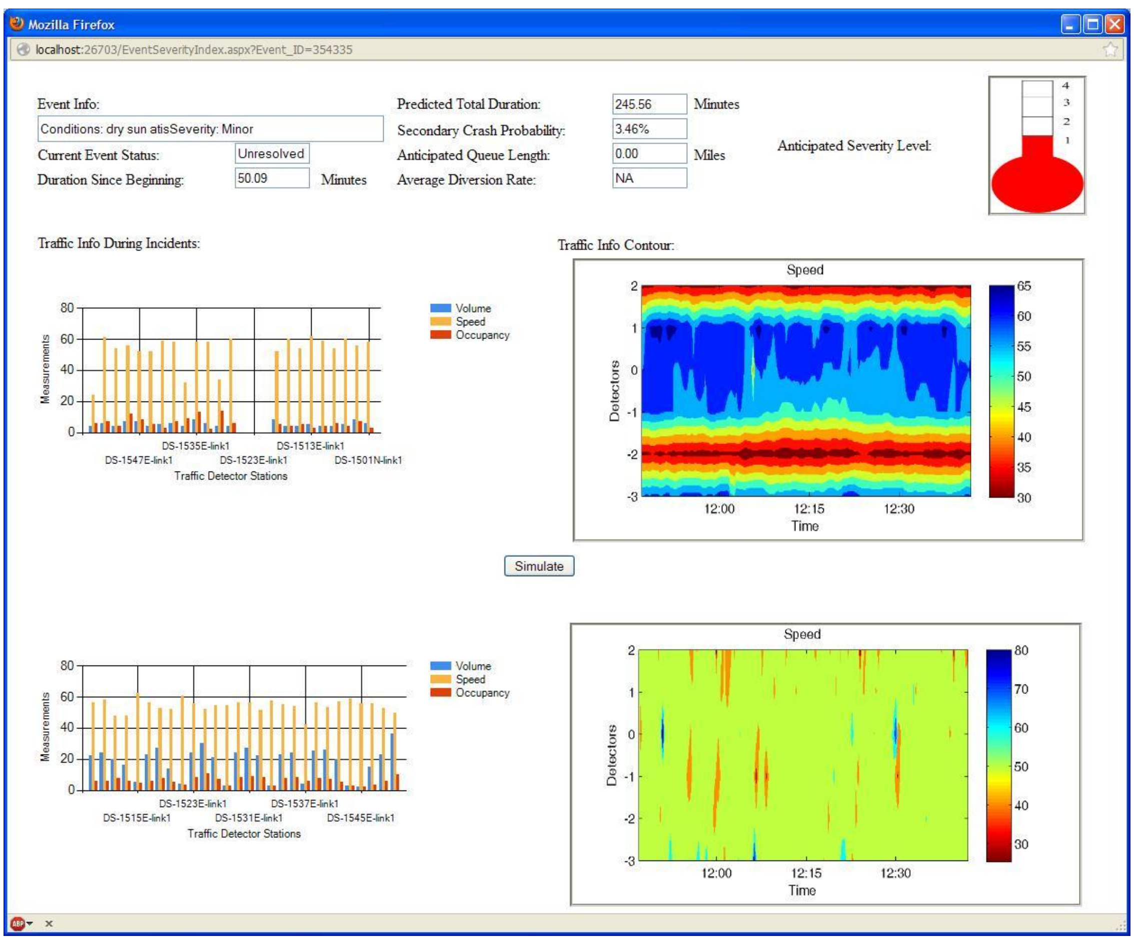


Figure 3-8 Incident Impacts Interface

Figure 3-9 shows the interface of the Camera Status data layer. When a user selects this data layer, the camera icons will show up in the map to indicate the locations of the CCTV cameras. The offline cameras will be indicated with the icons in gray. Left-clicking a camera icon will generate a callout window containing the detailed camera information, which includes:

- Name of TMC
- Camera ID
- County
- Status: Online/Offline

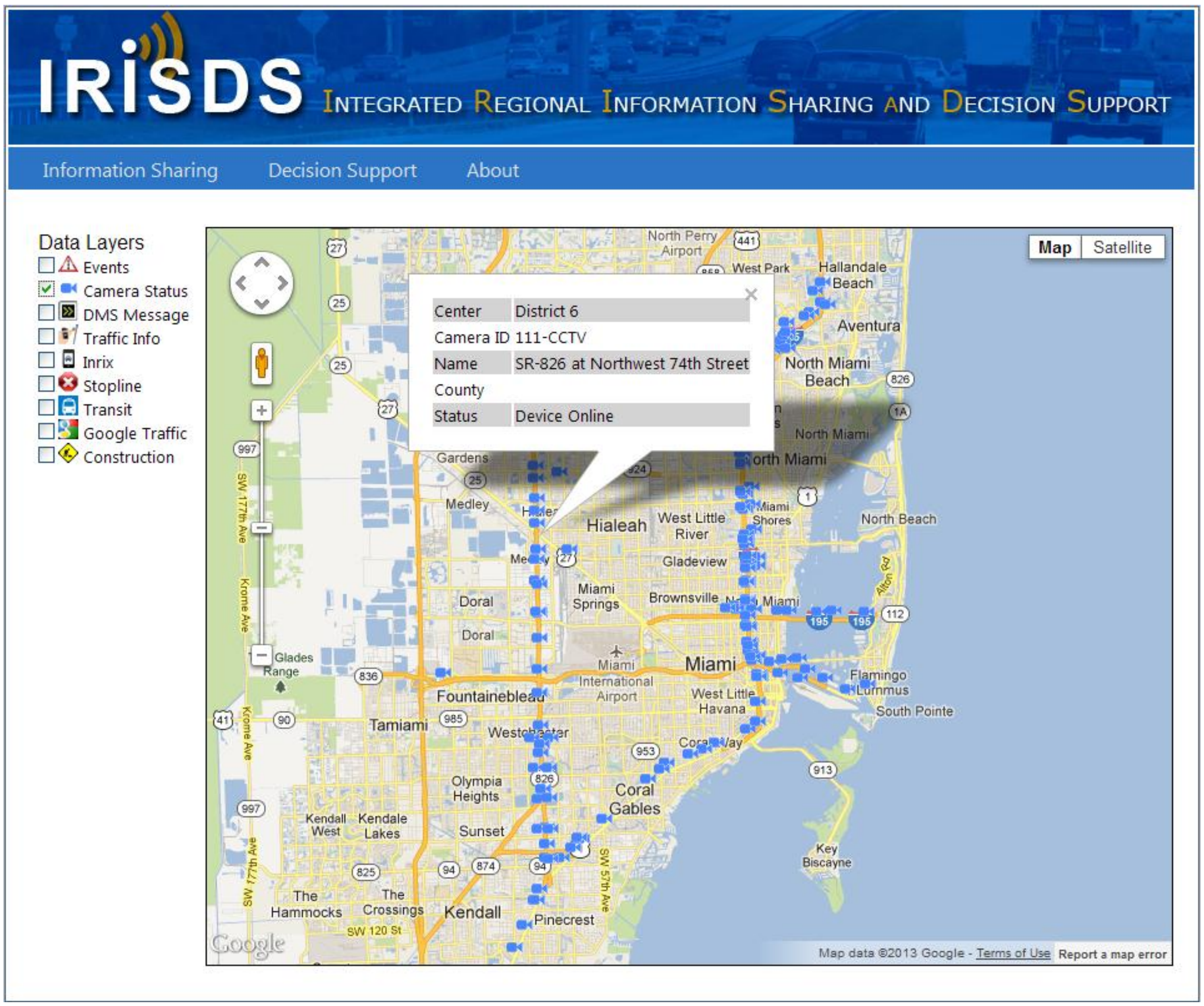


Figure 3-9 Data Layers – Camera Status

Figure 3-10 shows the interface of the DMS Message data layer. The locations of the DMS signs are indicated in this data layer by the DMS icons. The offline devices are displayed in gray icons. A callout window will pop-up by left-clicking a DMS icon, which contains the following DMS information:

- Name of TMC
- DMS ID
- Name of the DMS
- County
- Status: Online/Offline
- Beacon status
- DMS message
- Update time

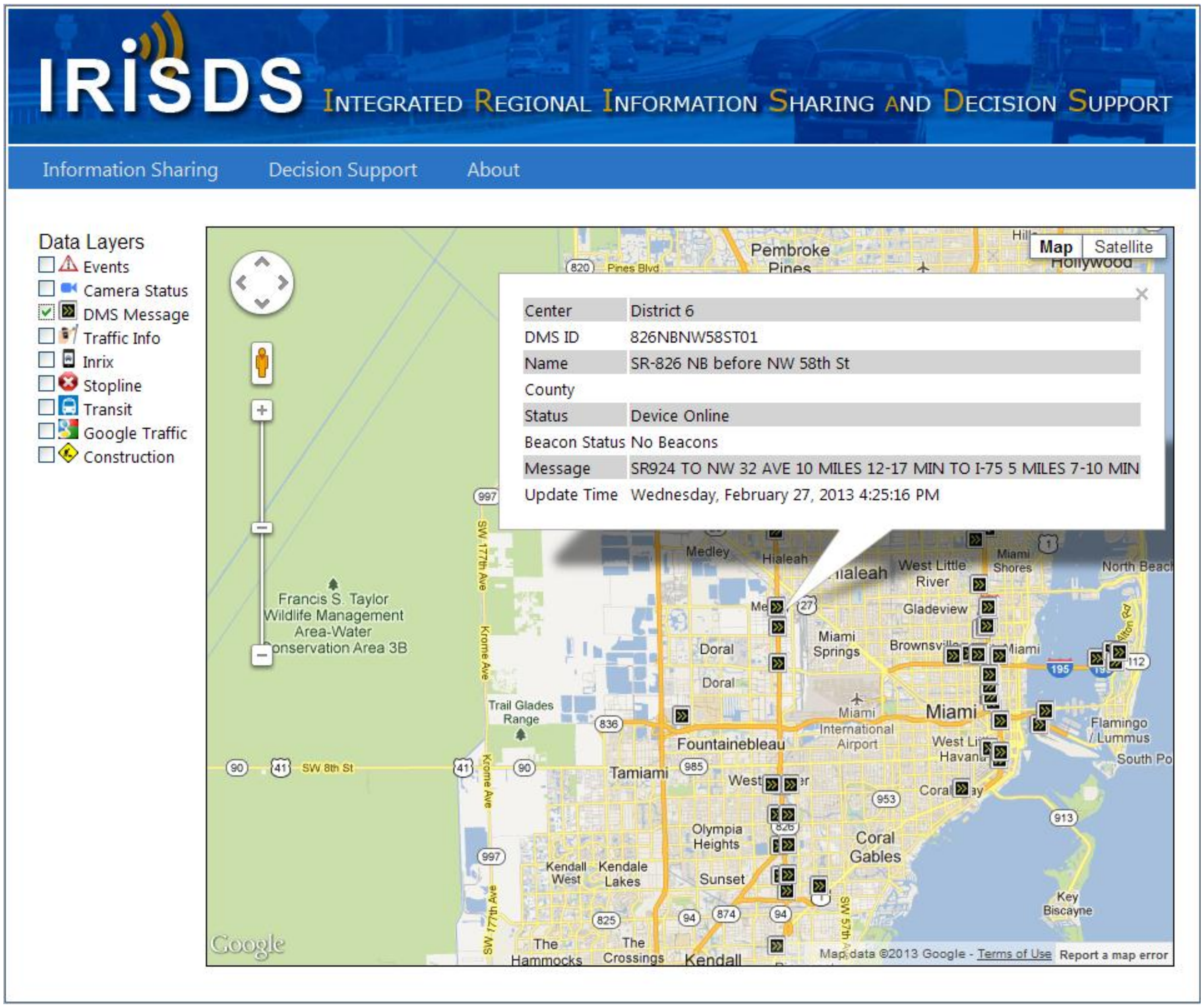


Figure 3-10 Data Layers – DMS Messages

A snapshot of the Traffic Information data layer interface is presented in Figure 3-11. As shown in this figure, the icons in the map indicate the locations of the detectors. The callout window shows the detailed traffic information, including:

- Node name
- Link ID
- Travel time
- Volume
- Speed
- Occupancy
- Update time

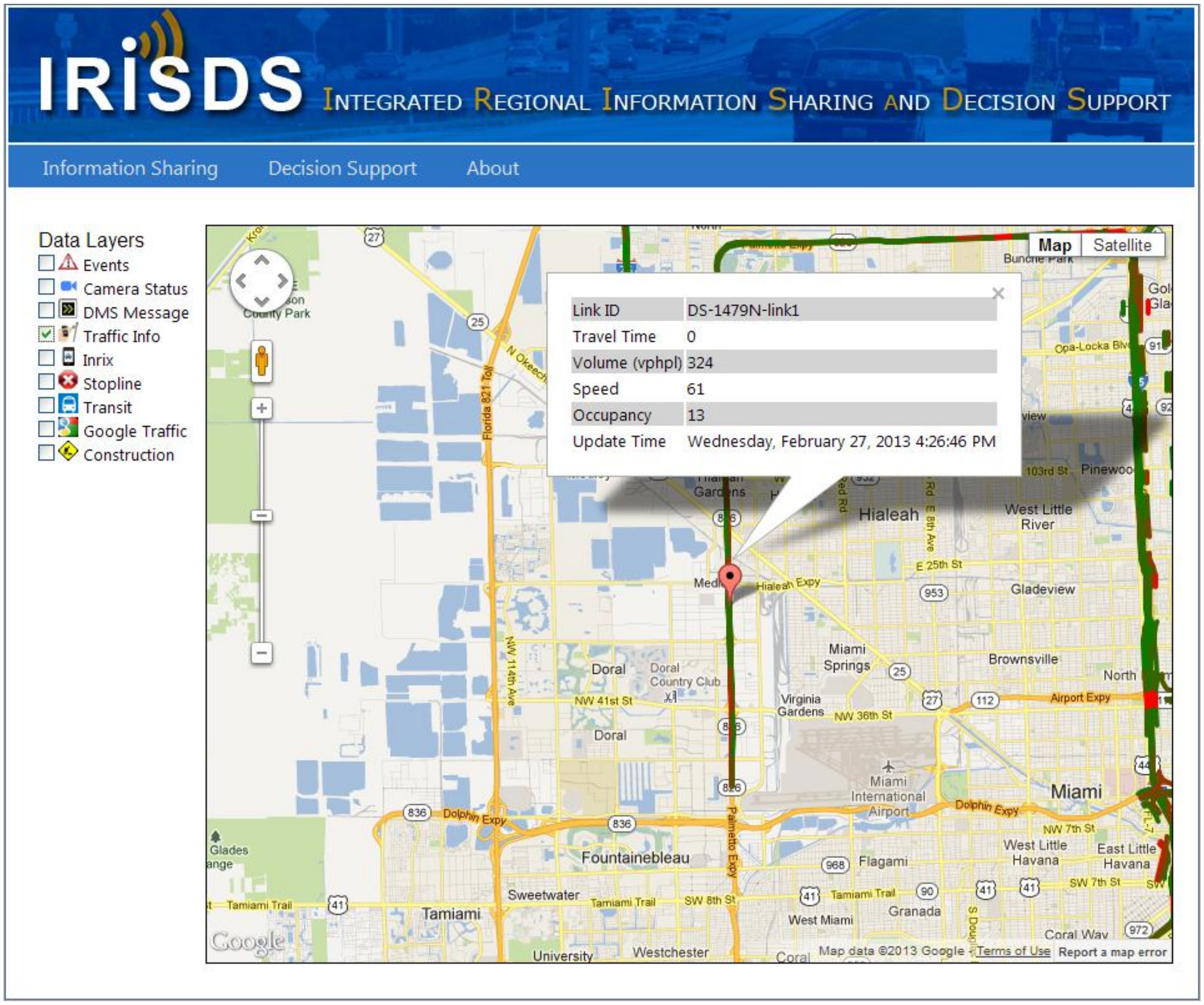


Figure 3-11 Data Layers – Traffic Info (Traffic Detector Data)

Figure 3-12 shows the interface of the INRIX data layer. Once this data layer is checked, the polylines will show up in the map to indicate the traffic data from INRIX. Left-clicking the polyline will generate a pop-up window containing the INRIX traffic data, as shown in Figure 3-13. The real-time speed and travel time, as well as the historical values for the selected roadway segment, are displayed in a chart. The detailed numbers are presented in a table below this chart. With this display, the users can identify any abnormal traffic conditions by comparing the real-time INRIX data with the historical values.

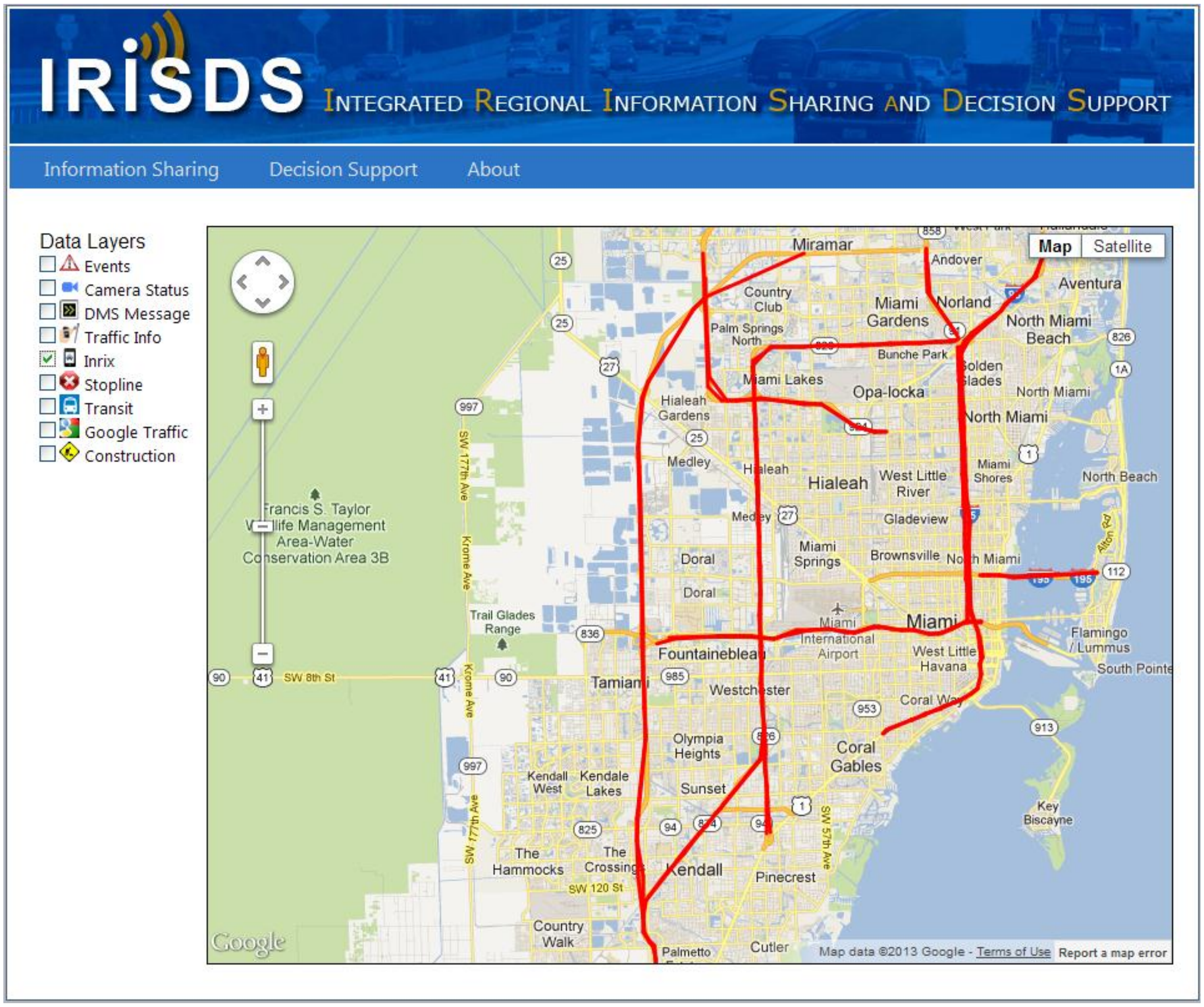
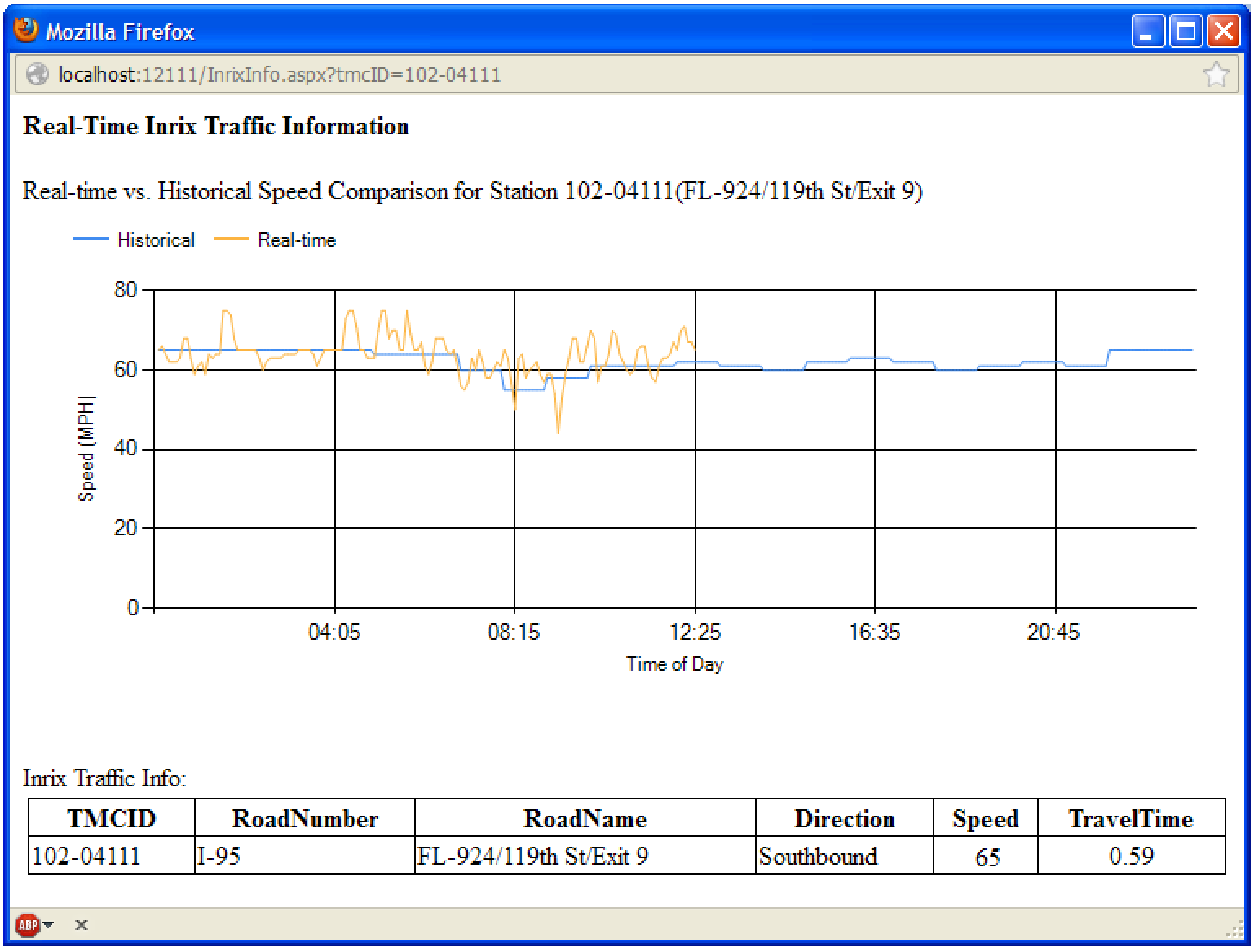


Figure 3-12 Data Layers – INRIX Data



TMCID	RoadNumber	RoadName	Direction	Speed	TravelTime
102-04111	I-95	FL-924/119th St/Exit 9	Southbound	65	0.59

Figure 3-13 Real-time INRIX Traffic Information

Figure 3-14 shows the interface of the Transit data layer. In this interface, the bus stop icons and polylines are shown in the map after users click the transit data layer to indicate bus stop locations and the route (including the two directions, eastbound and westbound) of the Kendall Cruiser (MDT Bus Route 288). The color of the segment between each neighboring pair of bus stops can change in real time to reflect the estimated passenger car travel speed on that segment, estimated as described in Chapter 6.

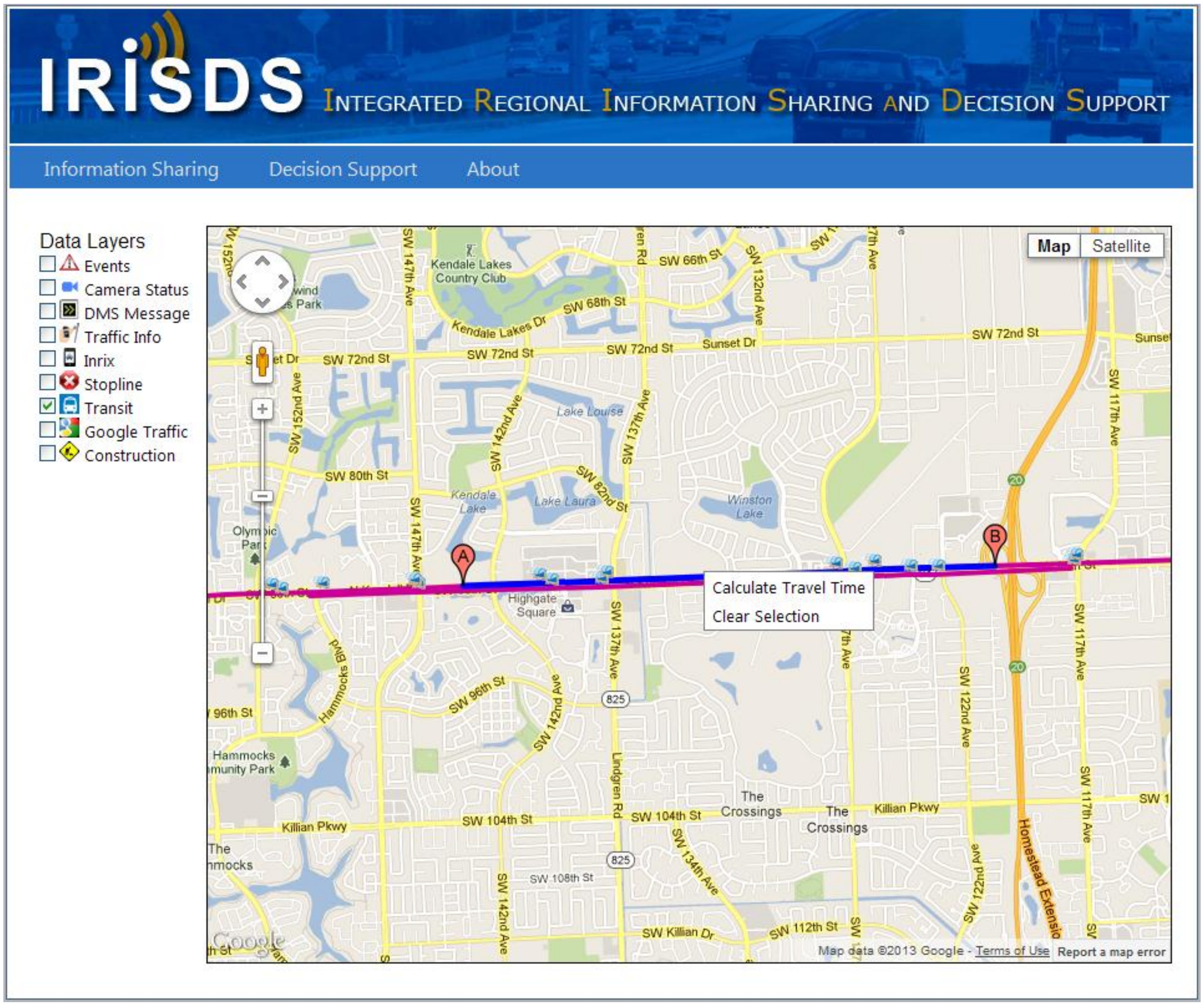


Figure 3-14 Data Layers – Transit Data

The user can also select any segment of interest between two points and calculate the estimated travel time and speed for both buses and passenger cars based on MDT bus AVL data (see Chapter 6). Right-clicking the bus polyline will generate a pop-up menu to define the starting point A and ending point B. The selected segment between points A and B will be highlighted in blue. Right-clicking the selected segment will generate a pop-up menu to allow the user to clear the selection or calculate the travel time. The travel time information will be shown in a pop-up window, as illustrated in Figure 3-15. This window allows users to select the date range, the time period (AM, PM, or All Day), and day of week to calculate the average travel time and speed for both bus and passenger car.

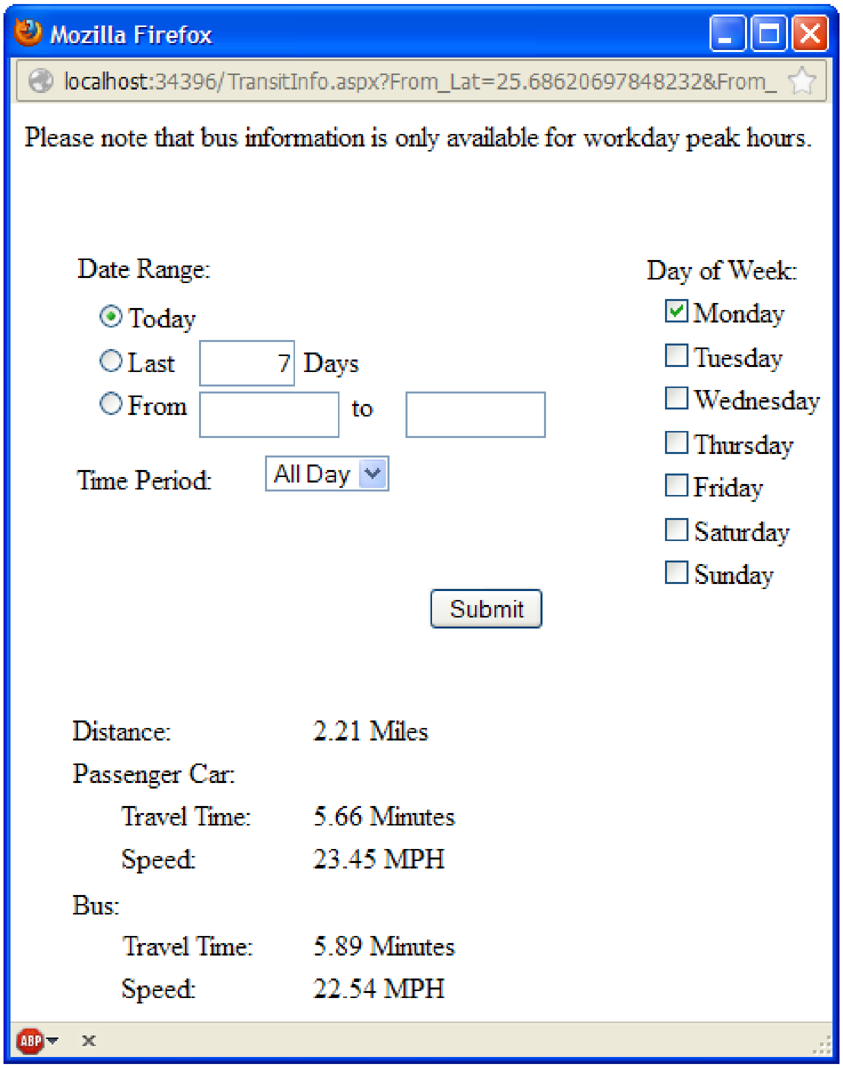


Figure 3-15 Transit Travel Time Calculation

Figure 3-16 shows the interface of the Google Traffic data layer retrieved from Google. Once this data layer is checked, the Google traffic information will show up in the map to indicate the traffic conditions of the roadways. This provides supplemental information to the abovementioned data.

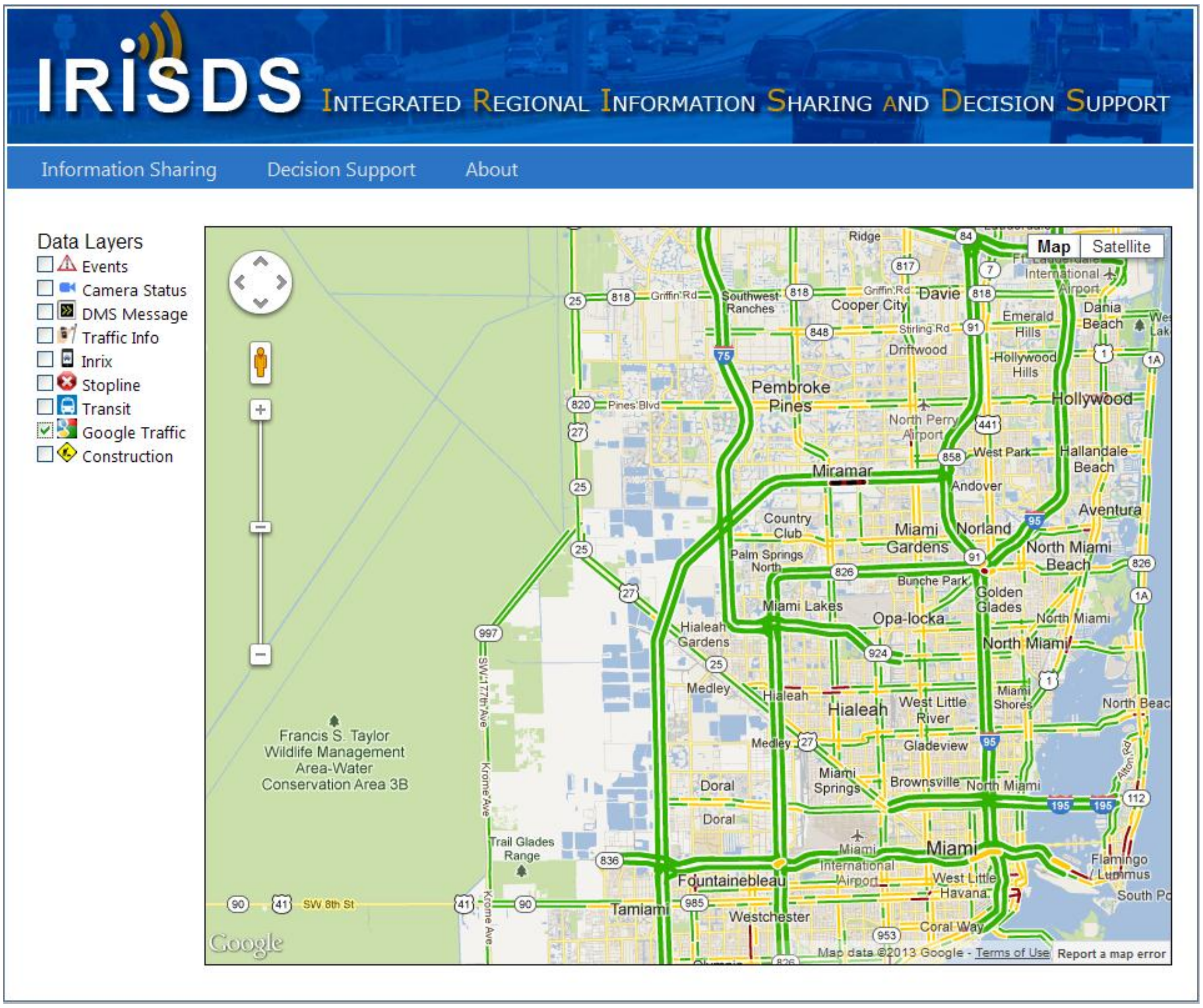


Figure 3-16 Data Layers – Google Traffic

3.4.2 Decision Support Tool Displays

There are three decision support tools that are currently available in the IRISDS: Incident Severity, Incident Diversion, and Transit Travel Time. They can be accessed under the Decision Support menu from the navigation bar.

Figure 3-17 shows the web interface of the Incident Severity decision support tool. The user can select the blockage type in terms of number of lane blockage, the corridor, and the event type (for example, Crash). Clicking the Get Incidents button will list all of the selected incidents in a table. The user can click the Compute Index button in the row of an incident to calculate the predicted incident severity index and generate the traffic information chart and contour.

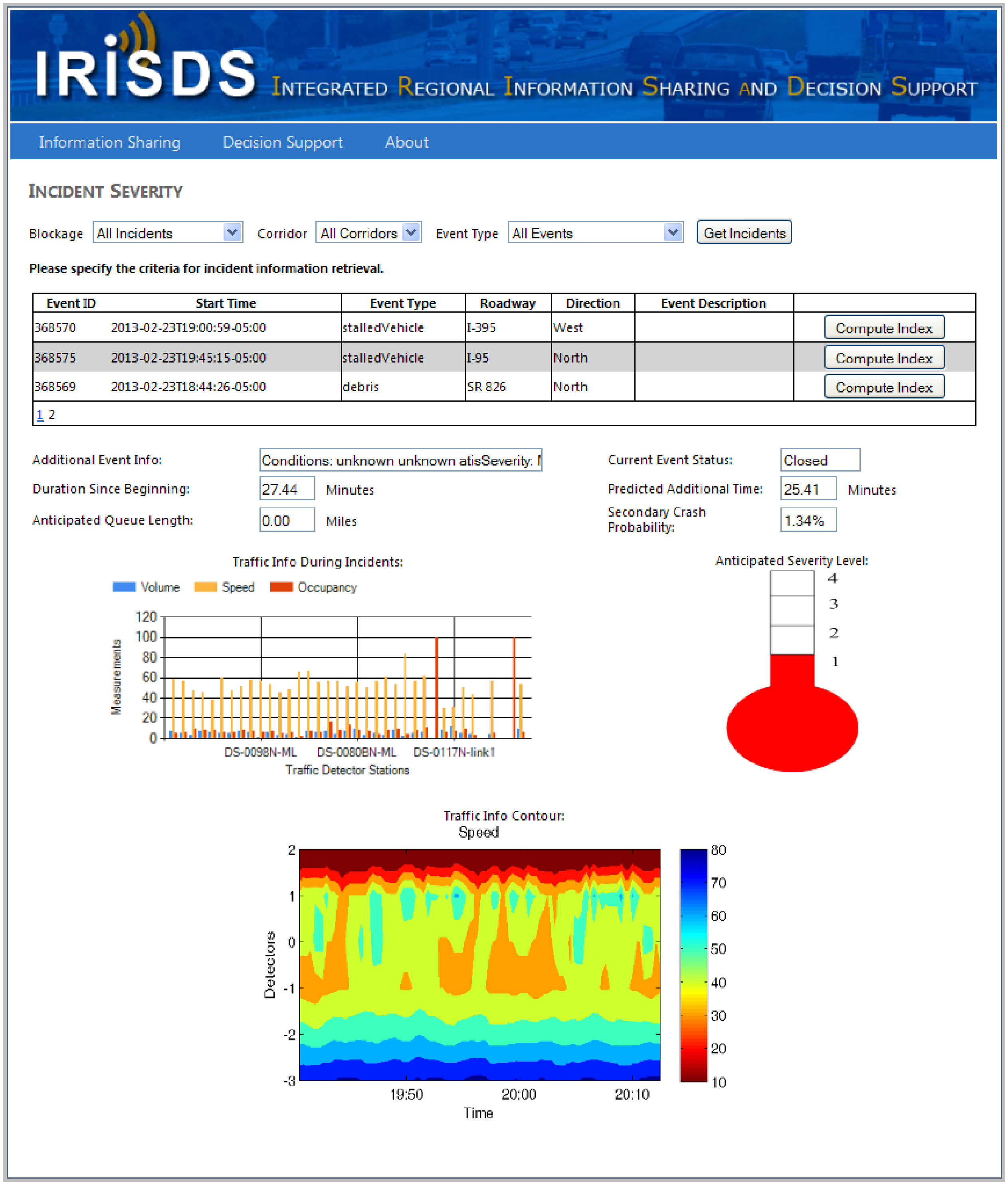
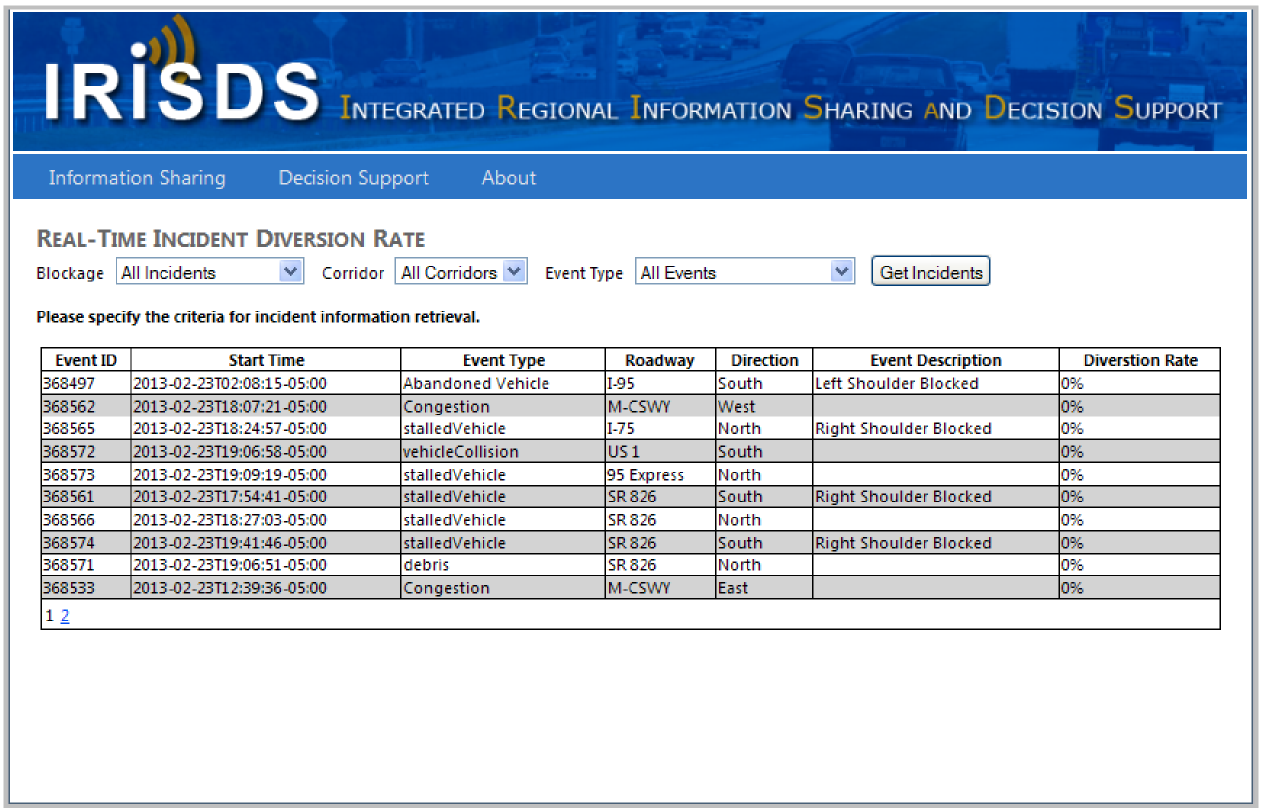


Figure 3-17 Decision Support – Incident Severity

The interface for the Incident Diversion decision support tool is presented in Figure 3-18. Similar to the Incident Severity tool, the user can select the blockage type, the corridor, and the event type. A list of incidents that satisfy the specified criteria will be listed in a table, as shown in Figure 3-18, by clicking the Get Incidents button. The diversion rate for each incident in this table is automatically calculated and listed in the last column of this table. Transportation agencies can manage their operations on the alternative routes based on the estimated diversion rate.



Event ID	Start Time	Event Type	Roadway	Direction	Event Description	Diverstion Rate
368497	2013-02-23T02:08:15-05:00	Abandoned Vehicle	I-95	South	Left Shoulder Blocked	0%
368562	2013-02-23T18:07:21-05:00	Congestion	M-CSWY	West		0%
368565	2013-02-23T18:24:57-05:00	stalledVehicle	I-75	North	Right Shoulder Blocked	0%
368572	2013-02-23T19:06:58-05:00	vehicleCollision	US 1	South		0%
368573	2013-02-23T19:09:19-05:00	stalledVehicle	95 Express	North		0%
368561	2013-02-23T17:54:41-05:00	stalledVehicle	SR 826	South	Right Shoulder Blocked	0%
368566	2013-02-23T18:27:03-05:00	stalledVehicle	SR 826	North		0%
368574	2013-02-23T19:41:46-05:00	stalledVehicle	SR 826	South	Right Shoulder Blocked	0%
368571	2013-02-23T19:06:51-05:00	debris	SR 826	North		0%
368533	2013-02-23T12:39:36-05:00	Congestion	M-CSWY	East		0%

Figure 3-18 Decision Support – Incident Diversion

Figure 3-19 shows the webpage of the Transit Travel Time decision support tool. The user can select a specific bus (or averaging of all the buses) and the bus route direction for transit travel time calculation. Clicking the Time-Space Plots button will bring out the time-space plots for both the bus and passenger car traffic. In these plots, the x-axis is the distance from the beginning of the route in each direction, and the y-axis is the corresponding cumulative travel time from the first bus stop to the current location. In addition to the real-time travel time plotted in these graphs, the average, 5th percentile and 95th percentile of travel time based on historical data, are shown in these two plots to assist the users in comparing current traffic conditions to historical values.

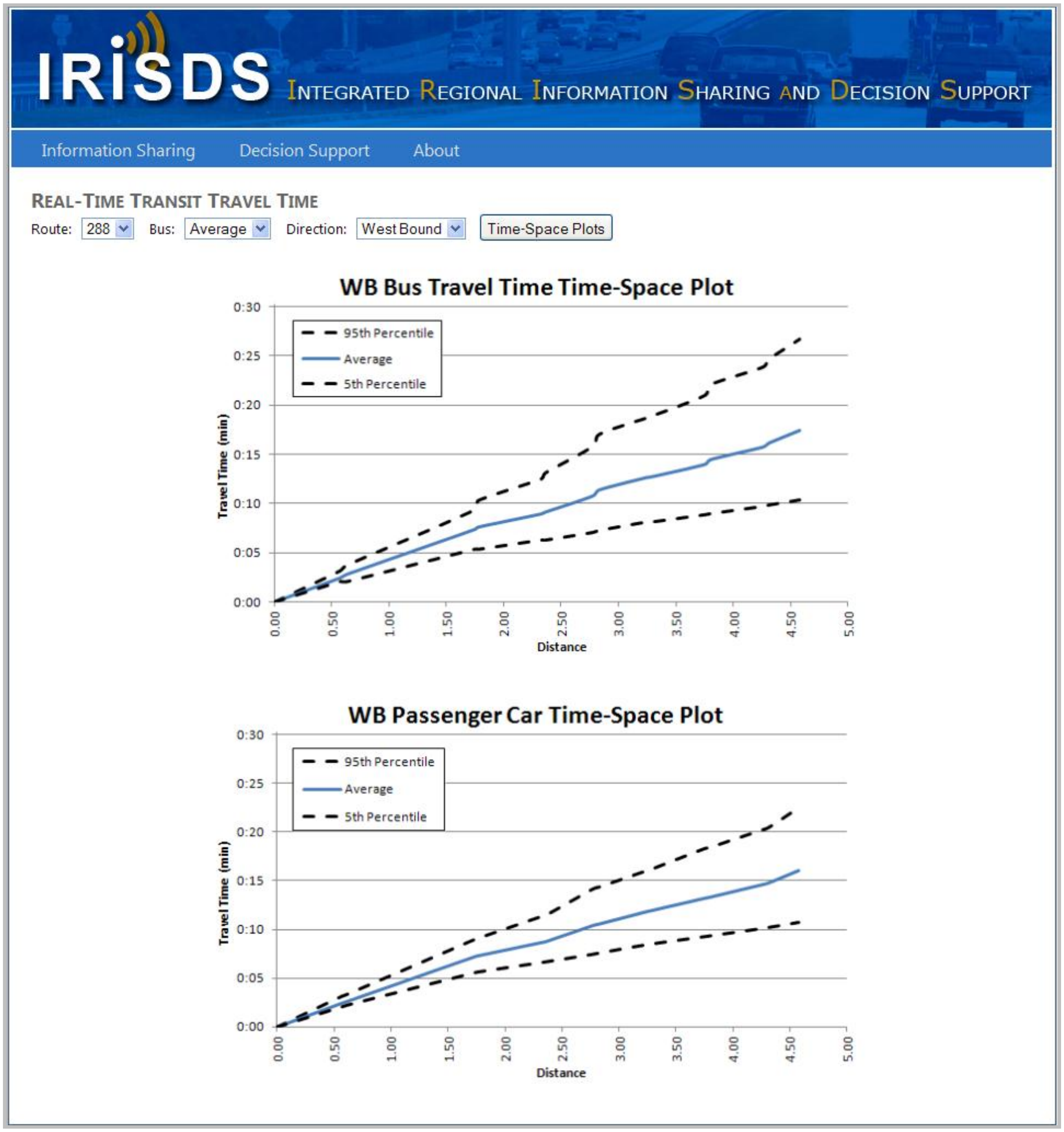


Figure 3-19 Decision Support – Transit Travel Time

3.5 References

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4 Incident Severity

4.1 Background

Traffic incidents have significant impacts on the performance of transportation systems. These incidents can reduce highway capacity and result in significant negative impacts on transportation systems. Traffic management centers (TMCs) have successfully applied advanced management strategies to reduce these impacts. However, the effectiveness of these management strategies can be enhanced by predicting, in real time, the impacts of incidents based on their identified attributes. The impacts can be further reduced by sharing the predictions with other agencies in the region, such as freeway management, arterial management, transit management, emergency management, and enforcement agencies. This will allow these agencies to provide better responses to incidents.

Due to the limited available information about incident impacts, transportation agencies have mainly used simple incident attributes, such as incident duration and lane blockage, to classify incidents by severity (*1*-*3*). The incident management program of the Florida Department of Transportation (FDOT) classifies travel lane blocking incidents into three severity levels based on incident duration and lane blockage information (*4*). Level 1 incidents are incidents with minor or no lane blockages and an estimated impact to traffic of less than 30 minutes. Level 2 incidents are intermediate traffic incidents with impacts to traffic estimated to be between 30 minutes to 2 hours. Level 3 incidents are major traffic incidents, which last for more than 2 hours or involve closing all mainline lanes or exit lanes. The above definition is also used by the FDOT TMC software to classify incident severity levels in real time. However, this definition requires the knowledge of incident duration, which is not known in real time until an incident is cleared. To address this difficulty, the current implementation in the FDOT TMC software uses a default of 30 minutes as the incident duration, and then reclassifies a lane blockage incident after 30 minutes and again after two hours, if the incident is not cleared by then.

Kachroo et al. (*5*) proposed the use of a more complex severity index to classify incidents. This index is calculated based on average incident delay (minutes per vehicle), incident duration, and incident type. However, utilizing such an index in real time requires the prediction of incident durations and associated delays.

This chapter first introduces the methods used for real-time prediction of incident impacts in IRISDS, including the prediction of incident durations, the potential for secondary incidents, and the traffic delays due to incidents. Then, this chapter presents an investigation of the use of a macroscopic simulation procedure based on the Highway Capacity Manual 2010 (HCM 2010) (*6*) and a microscopic simulation model to estimate traffic delays resulting from incidents.

4.2 Estimated Incident Impacts

IRISDS provides a number of measures to allow the assessment of incident impacts. The measures include the percentage lane blockage, incident duration, traffic delay, and the potential for secondary incidents. The percentage of lane blockage is received in real time through the XML stream from the FDOT SunGuide TMC in Miami, Florida. The values of the other measures are predicted in real time utilizing models, based on the available information received through the XML Stream.

The HCM 2010 does not provide guidance on incident duration estimation, and the approach developed by the authors in previous studies is applied (*7*). The incident duration is predicted differently in two sequential phases. Phase 1 is the initial phase where limited information is available about the incident. Such information normally includes day type (weekday versus weekend), starting time, location, and lane blockage. In Phase 2, additional information becomes available, including the responding agencies, injury levels, number and types of vehicles involved, and other information. In Phase 1, due to the limited information availability, complex prediction models cannot be used and a simple approach is thus utilized to predict incident duration based on historical data using the mean and 95% confidence interval of the durations of incidents of similar attributes to the current incident. In Phase 2, as additional incident attributes become available, a more detailed model for incident duration is used. The model used in this study was previously developed by the authors of this paper (*7*) utilizing the M5P tree algorithm as a basis for the prediction. Overall, the developed M5P model shows that the significant factors in predicting lane clearance duration are the number of blocked lanes, number of responding service patrol vehicles, injury presence, number and type of vehicles involved (tractor, truck, etc.), time of day (AM, PM, Midday, Night, Weekend), TMC verification and response time, incident type (Fire, Rollover, etc.), number of lanes blocked, presence of CCTV cameras, and presence of the Incident Response Vehicle (IRV) at the incident site. A thorough discussion of the used incident duration prediction model and its testing can be found in Reference *7*.

Another important impact of incidents is the potential for secondary crashes. IRISDS utilizes a logistic regression model developed by the authors in a previous study to assess the potential for secondary incidents in real time (*8*, *9*). The factors that were determined to be statistically significant in predicting the secondary crash likelihood in the model are lane blockage duration, queue length, time of day, and type of incident (accident or not). The details of this model can be found in References *8* and *9*.

This study investigates the use of a macroscopic simulation model based on the HCM 2010 procedure (FREEVAL) and a microscopic simulation model (CORSIM) to predict incident impacts on travel time. Below is a discussion of the use of these two tools to estimate incident impacts.

4.2.1 Macroscopic Simulation

FREeway EVALuation (FREEVAL) is the computational engine of the freeway facility analysis procedure of HCM 2010. It allows the analysis of freeway facilities consisting of connected basic freeway, weaving, merge, and/or diverge segments. FREEVAL identifies breakdown conditions and the impacts of such breakdowns over space and time, which is ideal for analyzing incident impacts. It utilizes shock wave analyses combined with other HCM procedures to assess the impacts of queuing, such as the case when the capacity drops due to incidents. FREEVAL 2010 works as a spreadsheet program with most of the computations embedded in

VBA (Visual Basic for Applications) modules. The tool allows the user to analyze a freeway facility of up to 70 freeway segments, for up to 24 fifteen-minute time intervals (6 hours).

Hadi et al. (*10*) compared the use of FREEVAL and deterministic queuing theory to assess incident impacts for off-line applications. However, no comparisons to real-world measurements of the impacts were conducted in that study. The analysis revealed that the HCM method produces similar results as queuing analysis for simple basic freeway facilities with non-varying demands. However, comparing the results using more complex cases shows that the queuing analysis produces lower incident delays than FREEVAL for the evaluated case study because of the inability of queuing analysis to model the interactions between segments of different types and geometries.

4.2.2 Microscopic Simulation

Microscopic simulation models have the benefit of being able to model complex roadway geometries, traffic control devices, integrated multi-facility (freeways and arterials) operations, variations in vehicle configurations, and variations in driver behaviors. Thus, utilizing these models can be proposed as a more detailed, flexible, and potentially more accurate approach for assessing the impacts of incidents and management strategies. In this study, the CORSIM microscopic simulation tool was investigated for use in assessing incident impacts.

The use of simulation at traffic management centers for real-time applications has been investigated by a number of researchers. Zou et al. (*11*) proposed an approach that combines a knowledge-based system and simulation for real-time incident management. Barceló and García (*12*) discussed a project that involves real-time simulation of alternative management strategies for use in providing recommendations for applications of these strategies. Barceló et al. (*13*) discussed the development of an “on-line” version of a microscopic simulation tool for applications at TMCs. The tool simulates control and information dissemination strategies, such as ramp metering, Dynamic Message Signs (DMS), and dynamic speed limit systems. Torday et al. (*14*) reported a real-time decision support system that is based on a combination of microscopic and mesoscopic simulation modeling.

A large number of studies have investigated methods to calibrate microscopic simulation models for recurrent conditions. For example, Volume 3 of the Traffic Analysis Toolbox series produced by the Federal Highway Administration (FHWA) (*15*) includes guidelines for calibrating traffic microscopic simulation modeling tools. Volume 4 of that series (*16*) presents guidelines that are specific to the calibration of the CORSIM microscopic simulation tools. However, very limited research has been done to identify methods to validate and calibrate simulation models for incident conditions. In a previous study, the authors of this paper developed a procedure that utilizes ITS data archives to calibrate simulation models for incident and no-incident conditions (*17*, *18*). It was concluded in that study that, when simulating incident conditions, the analyst should fine-tune simulation model parameters to produce the expected or measured drops in capacity during incidents and the expected impacts of incidents on various performance measures. Simply specifying lane blockages in the simulation, as has been done in some studies, is not sufficient to produce the expected impacts of incidents in the simulation. The methods developed in References *17* and *18* to calibrate microscopic simulation to model incidents were used in this study.

4.3 Estimation of Modeling Parameters

The two investigated traffic modeling methods utilizing CORSIM and FREEVAL require basic input parameters. These parameters include traffic parameters (volumes and free-flow speeds), incident duration, traffic demands, and capacity with and without incidents. In addition, to assess the accuracy of the delay estimations, it is necessary to measure real-world travel times with and without incidents to verify travel time estimation. The required incident duration can be predicted using the methods discussed earlier in this paper. The following sections describe the estimation of the other modeling parameters.

4.3.1 Florida ITS Data Archives

A number of the required modeling parameters were estimated based on archives of intelligent transportation systems (ITS) data maintained by the Florida Department of Transportation (FDOT). These archives are described in this section.

The Statewide Transportation Engineering Warehouse for Archived Regional Data (STEWARD) has been developed as a proof of concept prototype for the collection and use of ITS data in Florida (*19*). The current effort has concentrated on archiving point traffic detector data and travel time estimates. The STEWARD database contains summaries of traffic volumes, speeds, and occupancies collected from point traffic detectors.

In addition to the abovementioned system, the traffic management centers in Florida maintain incident management archives in Oracle database files. The incident archives include incident timestamps (detection, notification, responses, arrivals, and departures), incident ID, responding agencies, event details, chronicle of the event, and environmental information for all incidents in the region.

4.3.2 Estimation of Traffic Demand

The travel demands for the modeled system were estimated based on the ITS data archives mentioned above as well as historical tube counts and manual counts on the on-ramps and off-ramps. In a previous study (*20*), the authors of this paper developed procedures to estimate the demands in a system based on archived ITS detector data combined with other historical data. The procedure utilizes the k-means clustering algorithm to determine a typical day demand. During the incident day, this demand can be adjusted to account for the expected diversion and used as input to the simulation models. Readers are referred to the Reference *20* for a detailed description of this approach.

4.3.3 Free-Flow Speed

Another required parameter for freeway analyses is free-flow speed. The HCM 2010 provides an equation for the estimation of this parameter. However, the free flow speed could also be measured based on ITS detectors. The HCM 2010 mentions that the free flow speed on freeways is expected to prevail at flow rates between 0 pc/h/ln and 1,000 pc/h/ln (*6*). In this study, this definition was used to estimate the free flow speeds based on volume and speed data from the ITS data archive.

4.3.4 Estimation of Prevailing Capacity

The prevailing freeway capacity (with no incidents) at highway segments could be obtained based on traffic flow versus speed and traffic flow versus occupancy relationships at bottleneck locations. However, it is not possible to obtain the capacities on most highway segments on the freeway facilities because either they operate in uncongested conditions most of the time, or their congestion is mainly due to controlling bottlenecks downstream of their locations. In these cases, HCM procedures were used to estimate the capacities, based on various operation and geometry parameters, as described in the HCM 2010 (*6*).

4.3.5 Estimation of Drop in Capacity due to Incidents

A number of studies have investigated the reductions in capacity due to incidents. These capacity reductions were studied by Goolsby (*21*) in 1971. He concluded that an incident blocking one lane out of three lanes reduces capacity by about 50%. He also concluded that an incident blocking two lanes out of three lanes reduces the capacity by about 79%. HCM 2010 (*6*) provides estimates of the remaining capacity during incident conditions as a function of the number of the blocked lanes (or shoulder) and the number of lanes of the highway section under consideration (Total number of lanes per direction ranges from 2 to 8). The HCM estimates have been widely used in studies that investigated the effects of incident management strategies on system performance. A study by Qi and Smith (*22*) found, based on data collected in the Hampton Roads in Virginia, that the capacity reduction with one lane blocked out of three lanes can be modeled as a Beta distribution with an average of 63% and a standard deviation of 14%. The study also found that the capacity reduction due to two blocked lanes out of three lanes can be modeled as a Beta distribution with an average of 77% and a standard deviation of 12%. Knopp et al. (*23*) found that in the case of a blocked travel lane, the queue discharge rate for each available lane is reduced by 50%. They also found that the queue discharge rate is reduced by 30% when the driving lanes are open, but there is an incident on the shoulder or in the opposite direction of travel.

In this study, the reductions in capacity were estimated based on traffic detector volumes downstream of the incident location. However, at initial stages of the incidents and other instances when the drop in capacity cannot be estimated based on detector data, estimates based on the abovementioned sources or historical data can be used.

4.3.6 Estimation of Incident Delays

The real-world incident delays were calculated based on the archived travel time from the FDOT ITS detection system for incident day, compared to normal days for the same timestamps affected by the incident, including the recovery time period.

4.3.7 Estimation of Incident Severity Index

In order to obtain an overall assessment of incident impact severity level, it is expedient to combine the incident impact measures to produce a single severity index. This index and the estimated individual impacts and attributes can be communicated to the operator to allow a full assessment of the incident in real time. In this study, an ordered logit regression model was developed to obtain a combined severity index based on instances of actual real-world incidents with different estimated impacts and attributes. The impacts and attributes of the selected incidents were presented to ITS engineers. The engineers were asked to assign a severity level for each incident case. In this study, four severity levels are used, where level 1 corresponds to minor incidents and level 4 indicates most severe incidents. The results of this assignment were then used as input to an ordered logit regression model. The objective is to determine the relationships between the incident attributes and the impact severity levels, as identified by the ITS engineers.

The ordered logit model (also known as the proportional-odds model) is a linear logistic model which assumes that the intercepts depend on the category, but the slopes are all equal (*24*). Equation 4-1 presents a general form of the proportional-odds model.

$$\text{logit}\,(p_1) = \log(\frac{p_1}{1 - p_1}) = \alpha_1 + \beta' x$$

$$\text{logit}\,(p_1 + p_2) = \log(\frac{p_1 + p_2}{1 - p_1 - p_2}) = \alpha_2 + \beta' x$$

$$\vdots$$

$$\text{logit}\,(p_1 + p_2 + ... + p_k) = \log(\frac{p_1 + p_2 + ... p_k}{1 - p_1 - p_2 - ... - p_k}) = \alpha_k + \beta' x$$

$$\textit{and} \qquad p_1 + p_2 + ... + p_k + p_{k+1} = 1 \tag{4-1}$$

where P_1, P_2, .., P_{k+1} are the probabilities for being in categories 1 to $k+1$, α_1, α_2, .., α_k denote the intercept for each category, and β' is the coefficient vector.

A total number of 13 incident attributes was initially considered for fitting the regression model, which includes roadway, total number of lanes, number of lanes blocked, day of week, detected hour, fire or not, rollover or not, injury level, incident duration, historical demand, queue length, secondary incident probabilities, and delays. After the stepwise selection, the number of attributes included in the model is reduced to four, that is, number of lanes blocked, injury level, incident duration and delays. It should be mentioned that due to lack of severe incidents in the training dataset, only level 1 to level 3 severity indexes are present in the analysis. Table 4-1 summarizes the regression results.

Table 4-1 Ordered Logit Regression Model Results

Variable	Class Value	Estimated Value	Pr>ChiSq
Intercept	1	3.3504	<.0001
Intercept	2	6.431	<.0001
Number of Lanes Blocked	-	-0.5388	0.0296
Injury Level	-	-0.5619	0.0205
Incident Duration	-	-0.0321	0.0009
Incident Delay	-	-0.133	0.001

4.4 Case Studies

Two case studies were used to demonstrate the ability of the two traffic analysis methods (based on FREEVAL and CORSIM) to estimate traffic delays due to incidents. Both cases include one-lane blockage incidents that occurred along State Road 826 EB in Miami, Florida.

4.4.1 Case Study 1

Case study 1 was designed to show the ability of the two methods to estimate the delays, when the modeling parameters are modified to produce the exact drops in capacity, as measured by traffic detectors, for the specific incident under consideration. This case study assumes the availability of estimates of the drops in capacity from detector data in real time, and that model input parameters are modified accordingly to produce the estimated drops in capacity before running the model. Figure 4-1 shows the location of the incident of Case Study 1. This case study is for a real-world incident that started at 7:48 AM on December 12, 2008 and involved the blockage of one out of three lanes, followed by a shoulder blockage after the lane was cleared. At 8:02 AM, the crashed vehicles were moved to the shoulder and the incident ended at 8:45 AM. Using the M5P incident duration prediction model referenced earlier, the predicted lane clearance time was 17.3 minutes (compared to an observed time of 14 minutes). The additional shoulder blockage duration after the lane clearance was estimated to be 25 minutes, versus an observed value of 43 minutes.

Figure 4-1 Incident Location in Case Study 1
(Note: The numbers next to the incident represent the longitude and latitude of the incident location)

First, this incident was simulated in the CORSIM microscopic simulation software. As stated earlier, this case study requires calibrating the model to reflect the incident impacts on capacity. The drop in capacity was estimated, based on detector data, to be about 61%, which is close to the drop in capacity reported in the literature (*22*, *23*) but higher than the capacity drop according to HCM 2010, which is 51% (*6*). The capacity drop for shoulder blockage (after lane clearance) was estimated, based on detector measurements, to be about 30%, which is also close to the value reported Reference *23*, but higher than the drop according to HCM 2010, which is 17%.

The CORSIM model was calibrated in two steps, following the procedure used in References *17* and *18*, as discussed earlier. In the first step, the no-incident simulation was calibrated by modifying the free-flow speeds and the car following sensitivity factors and multipliers to replicate the observed measurements of speed and volume based on traffic detector data. In the second step, the capacity drops due to lane and shoulder blockages were replicated by adjusting the CORSIM rubberneck factor and incident length to replicate the 61% drop in capacity due to the lane blockage, and the 30% drop in capacity due to the shoulder blockage. The incident warning sign was also adjusted to produce a better lane changing behavior ahead of the incident.

The incident in Case Study 1 was also modeled in FREEVAL. Figure 4-2 shows a snapshot of input interface in FREEVAL. The highlight cell indicates the segment with incident. As with CORSIM, FREEVAL was also calibrated for no-incident conditions, as well as to reflect the drop in capacity due to incidents. The free-flow speeds of each roadway segment were calibrated based on traffic detector data. The capacities for these segments were set using the HCM 2010 procedures. The drops in capacity during the lane and shoulder blockages (61% and 30%, respectively) were also coded into FREEVAL. One of the difficulties in FREEVAL analysis is that the analysis time period must be segmented into 15 minute intervals. This creates difficulty in modeling incidents since the duration of most real-world incidents are not multipliers of 15 minutes. Thus, in this study, the FREEVAL model had to be run multiple times, and the overall incident delay was estimated by interpolation among the results from these runs. For example, in this case study, the actual lane blockage duration between 7:45 AM and 8:00 AM is 12 minutes, as the incident starts at 7:48 AM. Two situations were analyzed for this time period, one with a 15-minute lane blockage, and one without lane blockage. A similar approach was applied for the following time period (between 8:00 AM and 8:15 AM), as lane blockage continues until 8:02 AM. The results from the combinations of different cases are interpolated to produce the final results based on the assumption that incident delay is proportional to the square of incident duration, according to the queuing theory.

Input Worksheet - Directional Freeway Facility														
FREEWAY SYSTEM TITLE:														
SEGMENT NUMBER :	8	9	10	11	12	13	14	15	16	17	18	19	20	2
SEGMENT LABEL :	S08	S09	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S
Type (B, ONR, OFR, R, or W)	R	OFR	B	B	ONR	R	OFR	B	B	B	ONR	R	OFR	E
Length (ft)	609	891	252	2,449	954	546	954	1,800	1,000	130	877	623	877	2,9
Number of Lanes	4	4	3	3	3	3	3	3	3	3	3	3	3	3
FF Speed (Mi/hr)	64	64	60	60	62	62	62	63	63	63	65	65	65	6
Segment Demand (vph)	5,589	5,589	4,527	4,527	5,279	5,279	5,279	4,391	4,391	4,391	5,267	5,267	5,267	4,4
Capacity Adjustment Factor	0.98	0.81	1.12	1.00	1.11	1.11	1.11	0.97	0.36	0.97	1.07	1.07	1.07	0.
Origin Demand Adjustment Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.
Destination Demand Adjustment Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.
% Trucks	5.8	5.8	5.7	5.7	5.2	5.2	5.2	5.1	5.1	5.1	4.6	4.6	4.6	4.
% RV's	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.
On-Ramp Demand (vph)					752						876			
On-Ramp % Trucks					2						2			
On-Ramp % RV's					0						0			
Off-Ramp Demand(vph)		1,062					888						794	
Off-Ramp % Trucks		6					6						5	
Off-Ramp % RV's		0					0						0	
Acc/ Dec Lane Length (ft)		265			650		167				500		296	
Number of Lanes on Ramp		2			1		1				1		1	
Ramp on Left or Right (L / R)		Right			Right		Right				Right		Right	
Ramp FFS (mi/hr)		45			45		45				45		45	

Figure 4-2 Snapshot of Input Interface in FREEVAL for Case Study 1

Figure 4-3 presents the analysis results for travel time without incident. This figure shows that the travel time resulting from both CORSIM and FREEVAL are very close to the measured real-world travel time when there is no incident. Figure 4-4 presents the estimated and measured travel times under incident conditions when the predicted lane and shoulder blockage durations are used. As shown in this figure, the travel time estimated by FREEVAL is close to that obtained from CORSIM. However, both models underestimated the travel time when compared with the real-world data. This can be explained by the predicted lane and shoulder durations used in the simulation, which are shorter than the actual durations. To confirm that the main reason for the difference is the shorter blockage times, Figure 4-5 presents a comparison of total incident delay resulting from the analysis with real-world delays, when the predicted and the actual incident durations are inputted into the analysis. This figure also shows that when the predicted incident duration is used, the total incident delays produced by CORSIM and FREEVAL were significantly lower than the real-world values (about 41% and 46% lower, respectively). However, when the actual blockage durations were used, the total incident delay resulting from CORSIM and FREEVAL became significantly closer to real-world measurements (2.4% and 8.6%, respectively). These results indicate that the accuracy of the prediction of incident duration is important in order to increase the accuracy of the estimation of incident delays.

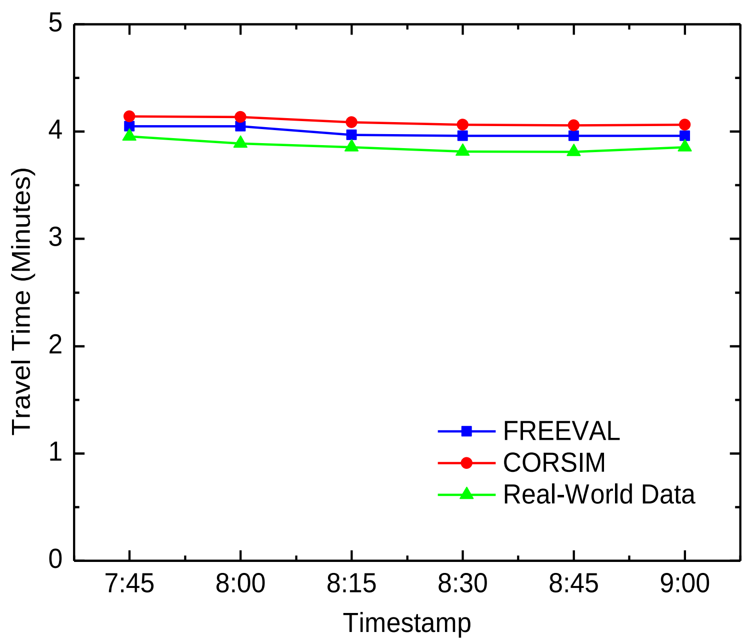

Figure 4-3 Travel Times under No-incident Conditions for Case Study 1

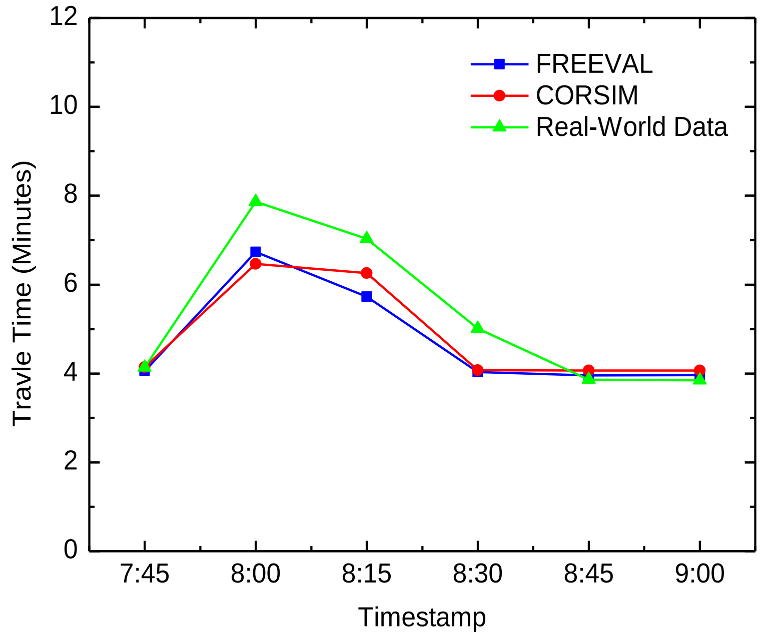

Figure 4-4 Travel Times during Incident Conditions for Case Study 1 with the Predicted Incident Duration

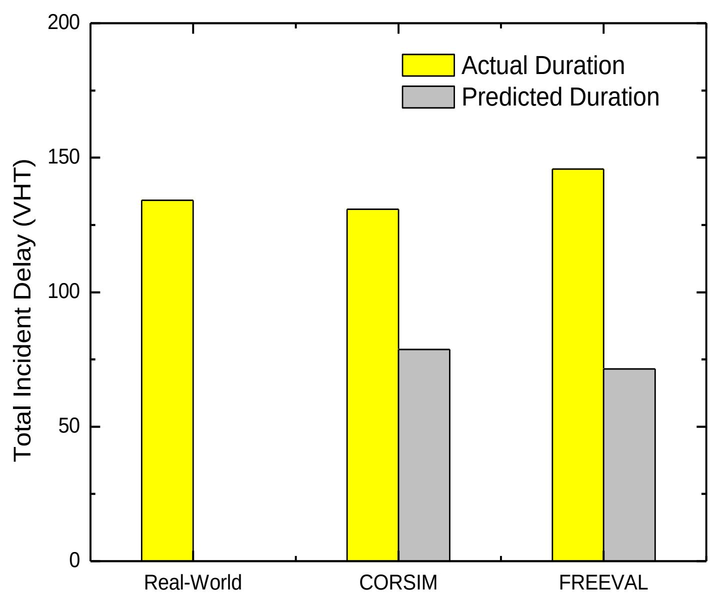

Figure 4-5 Total Incident Delay Comparison for Case Study 1 with Predicted and Actual Incident Durations

4.4.2 Case Study 2

Case Study 2 involves comparing the two incident impact estimation methods for a second incident without further calibration for the drop in capacity. This incident is similar to the incident in Case Study 1 in that it involves a one-lane blockage out of a total of three lanes, according to the incident database, and it occurs on State Road 826 EB. Thus, this case study investigates the use of a 61% drop in capacity due to lane blockage and a 30% drop due shoulder blockage (as was done in Case Study 1) as sufficient to produce good estimates of delays. This case study emulates conditions when it is not possible to recalibrate simulation models in real time to replicate the measured drops in capacity based on detector data, and thus default values of the drops in capacity are used based on the incident lane blockage attributes and locations.

The incident in Case Study 2 started at 10:33 AM on June 30, 2009, and after 13.3 minutes, the blocked lane was reopened. In this case, the predicted incident duration was 20.05 minutes. It should be noted that the predicted incident duration in this case is higher than the real-world duration, which is different from Case Study 1. Figure 4-6 presents a comparison of the estimated and measured travel times. When using the actual incident durations, both CORSIM and FREEVAL produced close results to each other, but also produced lower travel times compared to real-world data (51% vs. 54% lower). The analysis of the detector data for this incident revealed that the actual drop in capacity was 76%, which is higher than the 61% drop modeled in CORSIM and FREEVAL, based on the incident capacity drop used in Case Study 1. Figure 4-6 also indicates that the incident delays from CORSIM and FREEVAL became closer to that from the real-world, when the predicted incident duration was used. This happened by chance since the predicted incident duration, which is higher than the actual duration (20.5 minute versus 13.3 minute), compensates for the simulated lower capacity drop (61% versus 76%). If the predicted incident duration was lower than the actual duration, then the difference between the measured and simulated delays would have been higher than the difference when using the actual incident duration. Another interesting observation is that the time interval with the maximum delay is shifted from 10:45 AM to 11:00 AM when using the predicted incident duration, due to the longer incident duration. As stated above, the drop in capacity for this incident is significantly higher than those observed for one-lane blockage, although the operator entered one-lane blockage in the database. It appears that attributes other than the average number of lane blockage affected the capacity drop. The second incident is more severe in that it included three vehicles, compared to the first incident that involved only one vehicle. In addition, this incident included more emergency response vehicle activities. This further indicates the usefulness of measuring dynamically the drop in capacity, possibly at 5-10 minutes intervals in real time, considering the changing incident response activities at the incident site.

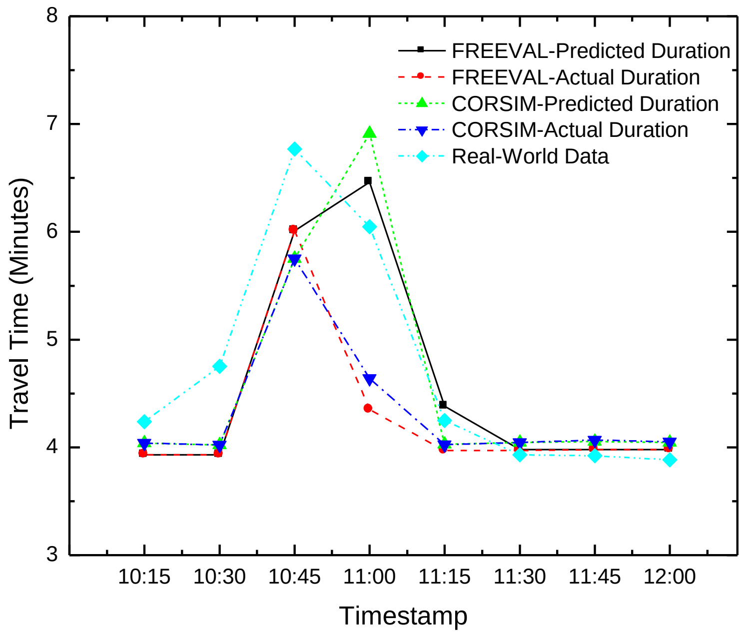

Figure 4-6 Travel Times under Incident Condition for Case Study 2

4.5 Conclusions

This study investigated the implementation of macroscopic and microscopic traffic simulation models to estimate incident delays, as part of a real-time traffic management system. Based on the results of this study, it can be concluded that both CORSIM and FREEVAL were able to accurately estimate traffic delays if the incident duration could be accurately predicted, the drop in capacity accurately measured, and subsequently, these two parameters are inputted into the tools in real-time operation. Both models produced estimates of incident delays that are similar to each other. The results presented in this study indicate that the accuracy of the prediction of delays due to incidents is affected by the accuracy of the prediction of incident durations and estimates of capacity drops. The predictions of these variables may be challenging due the stochastic nature of the variables. However, the development of advanced prediction models that are continuously updated in real time will allow for better estimation of the variables. In addition, it is essential that the TMC operators are trained to enter the correct number of blocked lanes and the times of incident blockages and clearance, as soon as they occur.

4.6 References

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5 Diversion Rate Estimation

5.1 Introduction

A number of technologies are used for disseminating traveler information, such as highway dynamic message signs (DMS), Highway Advisory Radio (HAR), traveler information telephone systems, and web sites. The disseminated information may encourage travelers to alter their route and avoid delays, especially during incidents. One of the most important parameters for assessing the impacts and benefits of these deployments that influence route selection is the diversion rates of travelers. In addition, the estimation allows the assessment of the guidelines and procedures of information dissemination. The estimation of diversion rates is also needed to assess the impacts on alternative routes, allowing agencies to select better signal control and other traffic management strategies on these routes during incident conditions.

Due to the limited information related to the actual diversion rate, most previous studies on the subject assumed certain values for this parameter in their analyses, in many cases, not on a strong basis. Several studies have been conducted to estimate the diversion rates, but the commonly used approach is to utilize stated preference surveys. A small number of studies have also utilized revealed preference surveys. With the availability of rich Intelligent Transportation System (ITS) data archives, it becomes logical to consider the use of traffic detector data combined with incident and construction data to provide a cost-effective method to estimate traffic diversions. However, a main challenge to such approaches is that traffic detectors are not installed on freeway off-ramps, as found in most ITS deployments. Many transportation agencies are not willing to install and maintain off-ramp detectors due to the additional costs involved. This prevents the direct estimation of diversion rates based on detector measurements of the volumes exiting the freeways during incidents. The objective of this study is to develop and evaluate a method to estimate the diversion rates based on freeway mainline detectors, without requiring measurements from on-ramp and off-ramp detectors.

5.2 Literature Review

Researchers have used Stated Preference (SP) and Revealed Preference (RP) to estimate the percentage of travelers diverting due to information provisions. In the SP methods, a survey of travelers is conducted that usually includes a series of hypothetical scenarios to be evaluated. The travelers are asked to make discrete choices between travel alternatives under different conditions. On the other hand, the RP approaches collect information on actual choice behaviors, either observed by the researcher or reported by the respondents to the survey. The advantage of the SP approach is the ability to control the choice contents and the independent variables of the model. The major limitation of this approach is that individuals are not committed to behave in accordance with their stated preference responses. Also, it is well recognized that the context and format of the survey affects the responses and thus can bias the results.

Several studies have conducted SP surveys to evaluate drivers' responses to DMS and other ATIS devices (*1-3*). Peeta et al. (*4*) conducted three different types of surveys (mail back, on-site, and Web-based surveys) to estimate the driver's response to DMS. The aim of the survey was to obtain information about drivers' responses to DMS (a driver's willingness to use the information posted on the DMS or not). The responses were related to a driver's familiarity with alternate roadways, estimated trip time, and socio-economic characteristics. The results of the study revealed that the content of the disseminated message had a significant impact on drivers' responses. For example, drivers were more willing to divert to alternate routes when the message posted on DMS indicated that the incident type is an accident. Khattak et al. (*5*) found that significantly more commuters diverted to alternate routes when the motorists were informed that the queue length was higher. Another study conducted by Madanat (*1*) concluded that approximately 5% of the drivers surveyed were willing to divert when the expected delays were greater than half an hour. A SP study conducted by Huchingson et al. (*6*) in Chicago showed that travelers are more willing to divert during the non-recurring conditions, as opposed to daily rush hour congestion. Commuters were more willing to take alternate routes when the incident occurred in the morning peak hours and are dominated by home-work trips. In general, studies based on SP surveys concluded that the disseminated information can result in up to 60% to 70% of freeway traffic exiting the freeway ahead of an incident location (*1*, *7-9*).

Limited information is available about the actual diversion due to traveler information, as reflected by field measurements or revealed preference. Several European field studies have found that the DMS compliance rate, that is, the percentage of vehicles diverting due to DMS messages, range from 27% to 44% (*10*). Knopp et al. (*11*) in another European study which found that for major incidents, up to 50% of travelers take another route.

Yin et al. (*12*) constructed time series curves based on the ratio of ramp volumes to the sum of ramp and mainline volumes for both incident days and normal days. The differences between these two time series were used in conjunction with dynamic programming to determine whether or not diversion exists. Note that the percentage of vehicles diverted cannot be estimated based on the Yin et al. (*12*) method, as well as the fact that the ramp volumes are required for this method. In addition, a binary logit model was developed to explore the relationship between diversion occurrences during incidents and contributing factors, such as number of lanes blocked, duration, and speed at the incident location.

As an example of studies that assumed diversion rates because of the unavailability of estimated or measured values of these rates, Luk and Yang (*13*) developed a simulation modeling framework to assess the performance of Advanced Traveler Information Systems (ATIS) under different conditions. They assumed the average diversion rate to be 15%, and the highest diversion rate to be 30%. Cragg and Demetsky (*14*) used the CORSIM microscopic simulation tool to analyze route diversion strategies from freeways to arterial roads. The study concluded that there was often an optimal diversion percentage beyond which the system delays increased. This diversion percentage is expected to vary in different systems, depending on traffic and incident conditions on the original and alternative routes.

With the advent of ITS, interest has increased in using data generated by ITS devices to assist in transportation performance measurements and decision-making processes. Huo and Levinson (*15*) conducted a study to evaluate the effectiveness of DMS located on the I-35E corridor in

Minnesota. A total of 45 messages displayed under different incident conditions were studied. Based on traffic data from loop detectors (including both mainline and ramps), a weighed probit model was developed to estimate diversion behavior. They found that the content of the message displayed on DMS had a significant impact on diversion behavior. After DMS installation, the travel time was reduced by 6.4%, and the delay was reduced by 5%, with a diversion of about 8%.

5.3 Traffic Management Data Archives

Archived traffic detector and incident databases are required as inputs for the methodology developed in this study. The traffic management centers in Florida maintain detailed incident management archives in Oracle database files. The incident archives include incident timestamps (detection, notification, responses, arrivals, and departures), incident ID, responding agencies, event details, chronicle of the event, and environmental information for all incidents on the managed corridors.

In addition to the incident archives, the Statewide Transportation Engineering Warehouse for Archived Regional Data (STEWARD) has been developed as a proof of concept prototype for the collection and use of ITS data in Florida (*16*). The current effort has concentrated on archiving point traffic detector data and travel time estimates. The STEWARD database contains summaries of traffic volumes, speeds, and occupancies collected from pointed traffic detectors in five-minute, fifteen-minute, or one-hour aggregation intervals, as requested by the user. The incident data and traffic detector data were extracted from the abovementioned two sources and associated with each other for use in the developed method, as described next.

5.4 Methodology

In order to estimate the average diversion rate for a given corridor, the methodology of this study utilizes a set of incidents and associated attributes that are extracted from the incident database. The selected incidents are then associated with measurements from traffic detector stations at locations upstream and downstream of the incident locations. The detectors can be located on freeways or urban arterial streets, depending on the study location. In the case study presented in this study, the detectors are located on a freeway. This association allows the determination of the diversion rate at each detector location, based on detector measurements. This is done, as described in more details later in this section, by calculating the difference between the average cumulative traffic volumes of typical no-incident days and the cumulative volumes for the incident day, based on mainline traffic detector measurements. Therefore, the average "typical" no-incident days and incident day traffic volumes need to be estimated before the diversion rate is calculated.

5.4.1 Traffic Volume Estimation

As mentioned above, the cumulative volumes for the no-incident and incident days are required for the methodology of this study. The volumes for the incident day is obtained based on extracted traffic detector measurements for the incident day. This requires the association of the timestamps and location of the incident with traffic detector data.

The identification of the typical no-incident days is accomplished using the *k*-means clustering algorithm. By examining the resulting patterns from the clustering, the analyst can clearly identify the typical day pattern on the corridor. It should be mentioned that if significant variations in traffic patterns are expected between the days of the week or months of the years, data filtering can be conducted to exclude the data for the months or days that are expected to have patterns that are significantly different from those of the incident day, prior to conducting the clustering analyses.

The utilized *k*-means clustering algorithm (*17*) categorizes the demand data for different days into patterns, based on the similarity of the time series of volume counts on different days. This is an iterative partitioning algorithm that minimizes the sum of time series distances to cluster centroids, summed over all clusters. In this study, the times series distance is measured by the Euclidean distance, defined as follows:

$$dist(v_j, c_k) = \sum_i (v_j(t_i) - c_k(t_i))^2 \ , \ \forall j \in k \tag{5-1}$$

$$c_k(t_i) = \frac{1}{n_k} \sum_j v_j(t_i), \forall j \in k \tag{5-2}$$

where the variable $v_j(t_i)$ represents the time series measurement *j* at time interval *i* from detector data, $c_k(t_i)$ is centroid of cluster *k* at time interval *i*, and n_k is total number of time series in cluster *k*. The optimization routine used in the clustering algorithm achieves a local optimum that can be varied each time the algorithm is run, depending on the starting point of the optimization. Thus, the algorithm is run for a number of replications to associate the measured demands with the clusters. The best number of clusters is determined by checking the within-cluster sums of point-to-centroid distances.

An example of the clustering results is the traffic data for microwave detector station 600641, located at the south end of NW 103rd Street, along the I-95 Corridor in Miami-Dade County, managed and maintained by FDOT District 6 Traffic Management Center (TMC), between January 1, 2011 and March 31, 2011, which were clustered into seven patterns, as shown in Figure 5-1. Patterns 1 and 2 are for days with detector malfunctions. Patterns 3 and 6 are clearly for incident days, as confirmed by examining the incident database. Patterns 5 and 7 are weekend traffic. Pattern 4 represents the normal day traffic at this detection station. Once the normal day pattern is identified, the average traffic volumes for normal day can be obtained by averaging the volumes for all days in the normal day cluster.

5.4.2 Diversion Rate Estimation

In order to estimate the diversion rates, the average volumes for the typical days, obtained as explained above, are used to represent the no-incident day volumes. The cumulative volume curves for the incident day and average typical day are then constructed, as shown in Figure 5-2, to estimate the diversion rates, based on the traffic demands. The symbol "P" in Figure 5-2 indicates the cumulative vehicle count when an incident occurs, and "R" represents the cumulative vehicle count when an incident ends. The symbol “S” refers to the differences in cumulative vehicle count due to diversion resulting from the incident.

Figure 5-2(a) shows that under the no diversion conditions, the cumulative volumes of the normal and incident day should be about the same by the end of the incident recovery period, after the queue dissipates. Figure 5-2(b) shows that if diversion occurs, the cumulative volume of the normal day will be higher than the cumulative volume of the incident day, at the end of the incident.

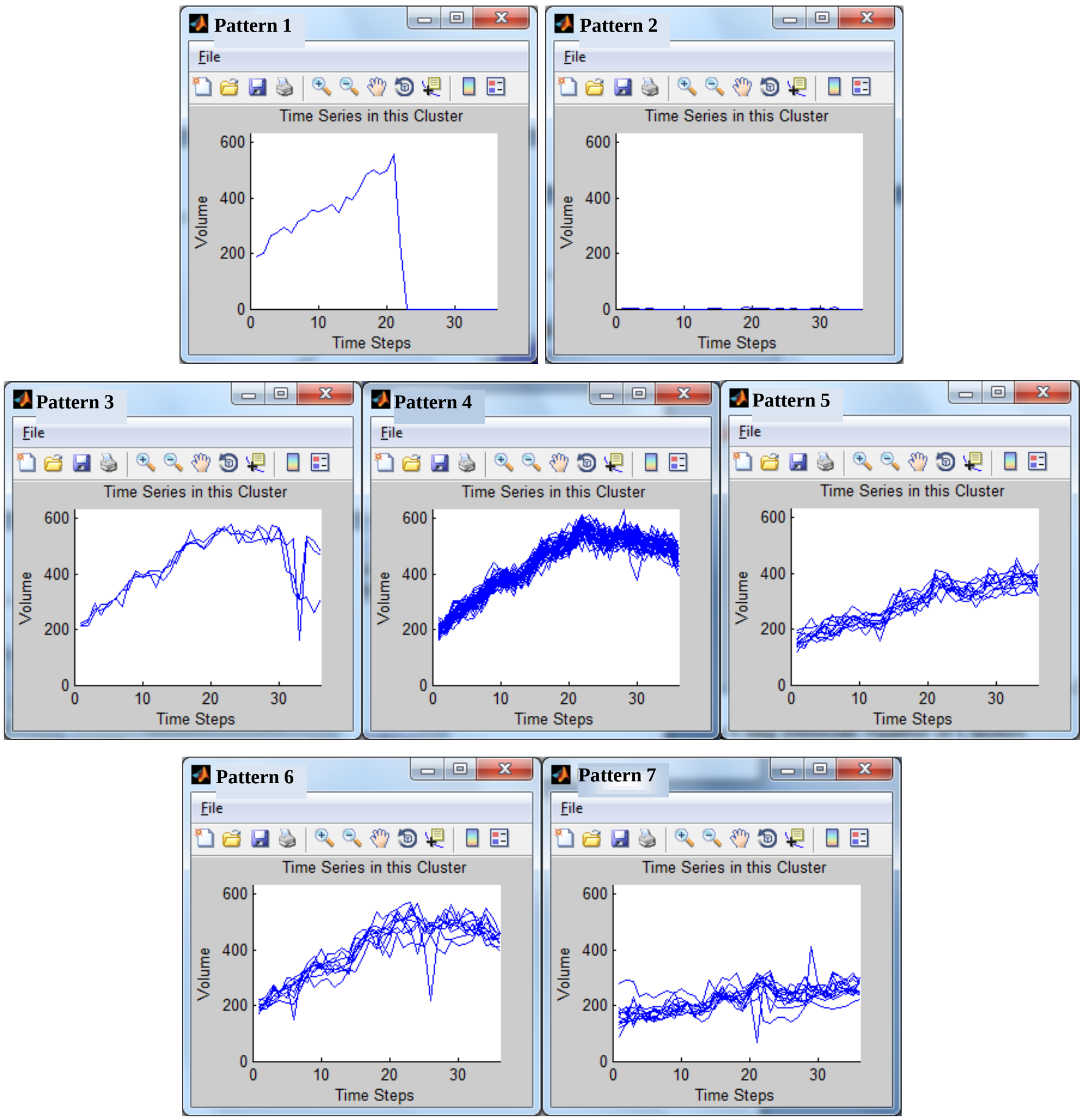

Figure 5-1 Example of Clustering Results

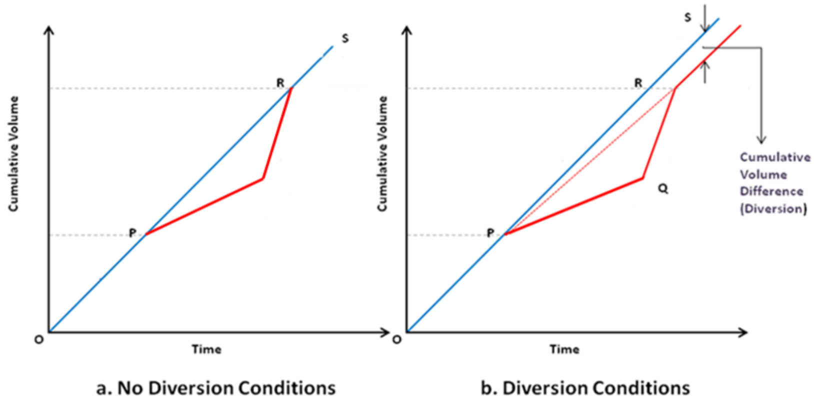

Figure 5-2 Cumulative Volume Curves under Diversion and No-diversion Scenarios

For each incident selected from the incident database, the cumulative traffic volumes are calculated based on detector data aggregated at five-minute intervals for each traffic detector station and for both the average typical no-incident days and incident days. The traffic diversion is then estimated as the cumulative volume difference between the average normal traffic day and the incident day over the analysis period. Let V_{ijN} denote the volume for time interval *i* at detector station *j* during normal traffic day conditions, and V_{ijI}, denote the volume for the time interval *i* at detector station *j* during a specific incident day condition. The mathematical expression for percentage of diversion rate due to incident, *D*, is as follows:

$$D = \frac{\sum_{i=t}^{t+\Delta t} V_{ijN} - \sum_{i=t}^{t+\Delta t} V_{ijI}}{\sum_{i=t}^{t+\Delta t} V_{ijN}} \times 100 \qquad (5\text{-}3)$$

5.4.3 Estimation of Incident Recovery Time

One of the challenges of the methodology described above is to identify the analysis period, for which the cumulative volumes have to be calculated. The cumulative volumes used in the calculation should include all of the periods, while the queue due to incident exists, as shown in Figure 5-2. A method was developed in this study to determine the time at which the queue is dissipated, based on detector data. The associated records in the incident database only report the timestamp at which the lane blockage ends, and there is no information about the timestamp when the traffic returns to normal conditions (recovery timestamp). In this study, a method was developed to identify the incident recovery time based on detector data. Starting from the timestamp of lane clearance, the speeds and/or occupancies of neighboring detectors around the incident are compared to the normal day values. When the difference of these parameters from their normal day values are consistently less than certain thresholds, the timestamp is considered the incident recovery time stamp. The following is the mathematical expression for this method.

$$\begin{cases} s_{i,j} - s_{i,j,n} \geq 0 \\ s_{i,j} - s_{i,j,n} < 0 \quad and \quad \left| s_{i,j} - s_{i,j,n} \right| < \varepsilon \end{cases} \tag{5-4}$$

where *s* symbolizes the speed. The subscript *j* represents the detector station, *i* indicates the time interval, and *n* refers to the normal day value. In this study, the speeds at the three upstream detectors and one downstream detector of the incident location were examined. The variable ε is the speed threshold with a default value selected as 5 mph. In order to avoid the fluctuations in detector data, this algorithm requires the detector speeds to satisfy the abovementioned threshold for a specified number of time intervals. The default is two intervals, considering a detector data aggregation level of 5 minutes.

5.5 Methodology Application

Since the manual application of the method described above for calculating diversion rates is time-consuming, the method was implemented as part of a computer program to automate the process. This computer program contains three modules: the first is to select potential incidents to include in the analysis based on the criteria identified by the user. The selection criteria can consider attributes such as the analysis corridor(s), direction of the freeway, day of year, time of day, incident type, and lane blockage conditions. The second module implements the pattern identification algorithms to determine the typical no-incident day traffic volumes. The third module performs the traffic diversion rate calculation based on the extracted information. The case studies presented below were conducted using the developed computer program.

Verification of the developed methodology involved the examination of traffic diversions during three real-world incidents, which were then compared with ground truth measurements of the diverted traffic. These three incidents occurred along the I-95 southbound direction in Miami-Dade County, Florida. Figure 5-3 illustrates the location of the study corridor. Table 5-1 summarizes the main attributes of the selected incidents. The actual diversion rates for these incidents were obtained by counting the mainline and off-ramp traffic volumes during the incidents, as well as under the normal conditions based on videos collected from closed circuit television (CCTV) cameras located every mile. The estimated diversion rates utilizing the developed methodology described earlier were compared to these manually counted values, and the results are presented in Figure 5-4. As shown in this figure, the estimated diversion rate for these incidents is in general within 4% from the measured diversion in terms of absolute values of the percentages diverted, which is reasonable considering that an average approximate value of the diversion is needed for the purpose of this study. Note that the difference between the estimated value and actual value can be further minimized if the developed model is based on data that include those from off-ramp detectors.

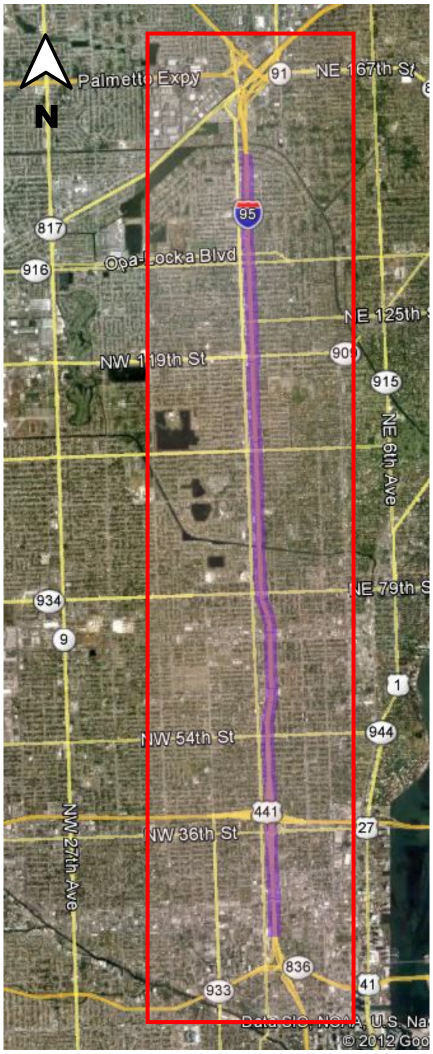

Figure 5-3 Study Corridor

Table 5-1 Main Attributes of the Three Incidents Examined

Index	Detected Date	Number of Lanes	Number of Lanes Blocked
Incident 1	2/28/2012 8:45 AM	4	2
Incident 2	3/26/2012 4:28 PM	4	2
Incident 3	7/20/2012 3:06 PM	4	1

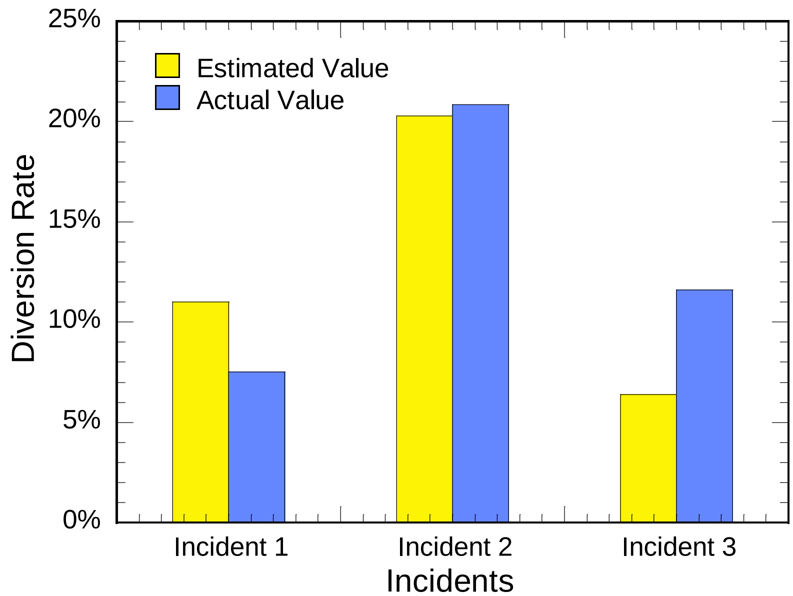

Figure 5-4 Diversion Rate Comparisons

The next step was to use the developed method with a larger incident database to determine if a general relationship can be obtained between the number of blocked lanes and the diversion rate. The selected study corridor is also the I-95 corridor in Miami, Florida, including both directions of travel. The considered section of the corridor is located between the Golden Glades interchange (a multilevel interchange between I-95, Florida Turnpike, SR-826, SR-9 and US-441) and SR-836 (just north of downtown Miami), with a length of about 7 miles and 8 interchanges. The managed lanes and ramp signaling are implemented along this section, too. The total number of general purpose lanes along this section is four or five, depending on the segments, and the total number of managed lanes is two. The average lane width is 11 feet. Traffic detector data were obtained from the detector data warehouse to estimate the diversion rates (*16*). All incidents that occurred on the general-purpose lanes between 6:00 AM and 7:00 PM on weekdays from January 1, 2011 to June 30, 2011 within the study area were reviewed, and only the incidents with at least one-lane blockage are used in the analysis. The travelers along this corridor section can receive the incident information mainly through DMS messages, 511 traveler information telephone systems, and the media. To account for the fact that the incident detection time recorded in the incident database may lag behind the actual occurrence time of incident, the diversion rate calculation starts at a timestamp that is earlier than the incident detection time (15 minutes earlier was used in this study). Table 5-2 presents the diversion rate estimation results. As shown in this table, a total number of 188 incidents were considered. The available incident sample size varies depending on the number of lanes of the corridor segment and number of lanes blocked.

The results in Table 5-2 show that there appears to be a general relationship between the number of blocked lanes and diversion, as expected. For example, when the total number of lanes is four, the average diversion rate increases from about 11% for one-lane blockage incidents to about 35% for full lane blockage incidents. It can also be seen from this table that, in general, for a given number of blocked lanes, there is a trend of reduction in the diversion, as the number of the available open lanes increases.

Table 5-2 Diversion Rate Estimation Results

Number of Lanes	Number of Lanes Blocked	Average Diversion Rate	Sample Size
3	1	14.81	28
3	2	10.68	3
3	3	30.27	3
4	1	11.07	70
4	2	16.88	27
4	3	24.61	7
4	4	34.83	3
5	1	8.60	25
5	2	9.87	18
5	3	17.3	4

The values presented in Table 5-2 were further fitted into a linear expression using a linear regression analysis that relates the average diversion rate with the lane blockage ratio, which is the ratio between the number of lanes blocked and total number of lanes under normal conditions. Note that the cases with the small sample sizes (less than 4 samples) are not included in the analysis since these results may not be representative due to limited sample size. The derived expression was as follows:

$$D = 33.949 \times R \quad (5\text{-}5)$$

where the variable D is used to represent the average diversion rate in percentage, and R is the ratio between number of lanes blocked and original number of lanes. As seen from Figure 5-5, the model fit the data relatively well with a modified R-square of 0.8. This expression indicates that there is a general trend of increase in diversion, with the increase in the percentage of lanes blocked by the incidents.

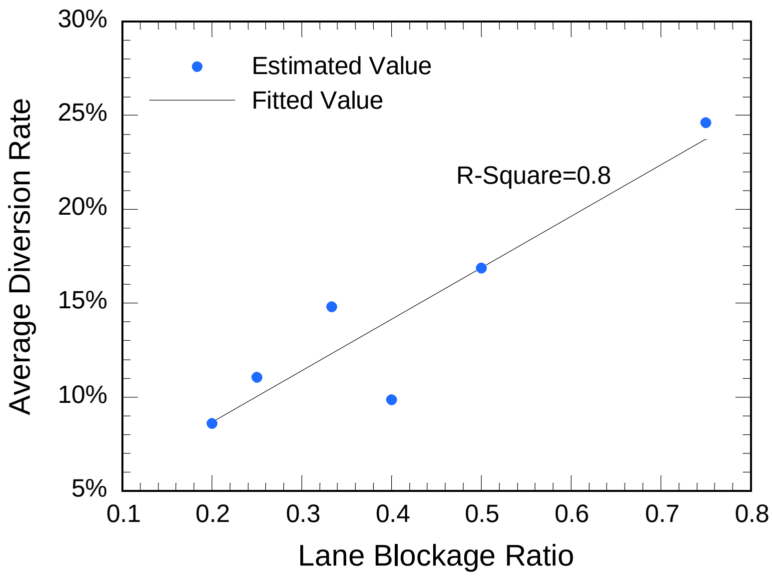

Figure 5-5 Relationships between Average Diversion Rate and Lane Blockage Ratio

5.6 Conclusions

A new methodology was developed in this study to estimate the diversion rate during the incidents based on mainline traffic detector data. The validity of developed methodology was verified by comparing the estimated values with real-world data. Case studies of the developed method indicate that the average diversion rate is about 10%-35% for 3-lane and 4-lane roadways, depending on the number of lanes blocked. A linear relationship between average diversion rate and lane blockage ratio was also developed, which indicates that there is a general trend of increase in diversion with the increase in the ratio of the lanes blocked by the incidents.

The methodology developed in this study can be used to estimate the diversion for the corridors under investigation based on detector data. It can also be used to derive relationships to estimate traffic diversion similar to the relationship derived in this study for use in the evaluation and benefit-cost analysis of traveler information systems. If a larger incident sample size is available, it will be possible to investigate the impacts of incident attributes, such as incident duration and time of occurrence, and traffic parameters, such as congestion levels on the corridor and alternative routes, on the diversion. In addition, other independent variables, such as predicted incident delays and queues, can be included in the diversion estimation. Developing more advanced models as stated above will require the implementation of predictive modeling capabilities to estimate such parameters as incident durations, delays, and queues in real time.

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6 Travel Time Based on Transit AVL Data

IRISDS was developed as a proof of concept of how data from different agencies in the region can be used to provide information to support the operations of the transportation system in the region. Automatic Vehicle Location (AVL) systems aboard buses could provide worthy data that can be used to estimate travel times of both transit and general traffic vehicles. This section presents a discussion of an IRISDS module that was developed to utilize Kendall Cruiser AVL data received in an XML data stream from MDT as probe to estimate bus and general traffic travel times on Kendall Drive in Miami.

6.1 Previous Research

In the late 1990s, Dailey et al. (*1*) developed travel time estimation algorithms for online real-time traffic information in Seattle, Washington, that utilized the AVL of transit buses as speed probes. A significant amount of effort was put into processing raw bus probe speeds before the traffic information could be extrapolated. Kalman filtering and exponential smoothing techniques were both used in this process. Their study showed that: 1) on one of the freeway segments, bus speeds were on average 12.8 kilometers per hour (km/h) (8 mph) lower than automobiles; and 2) on one of the primary arterials, the study found that instantaneous travel times produced by this method lagged in response to changes in traffic along a corridor.

Pu and Lin (*2*) utilized transit buses as probes to detect general vehicle traffic conditions. The study pointed out that the feasibility of such an application largely depends on a) the existence of quantifiable relationships between bus traffic and general vehicle traffic; and, b) adequate frequency of bus travel sample size to infer real-time general vehicle traffic conditions. The findings of the study suggest a framework for real-time bus probes by utilizing both historical bus-car speed relationships and real-time bus travel information.

Later, Pu and Lin (*3*) identified statistically significant relationships between bus and car speeds using historical real-time AVL bus data and test car data on a signalized urban street in Chicago.

This study found that bus-car speed relationships were location specific, as follows: 1) at mid-blocks, buses and cars exhibit similar speed patterns with or without constant differences; 2) at bus-stop-only locations (where no control is imposed on non-transit vehicles), bus and car speeds could have sharp contrasts, as buses have to respond to passengers' demands, while cars could travel freely if not disturbed by buses; and, 3) at controlled-intersections, both buses and cars are subjected to the same control strategies (assuming no transit priority strategy is implemented) but buses tend to have slower start-up and slow-down (i.e., longer acceleration and deceleration distances) than cars.

The advantage of using transit travel time is that it utilizes GPS data that is already available. The disadvantages of this method are: 1) the need for quantifiable relationships between bus traffic and general vehicle traffic that should be calibrated for each location; 2) the lack of sufficient sample size in many locations because of infrequent bus travel observations.

6.2 Utilized Data

The study was conducted on the Kendall Cruiser bus route 288, a service provided only on weekday rush-hour service. This route runs on Kendall Drive, which serves as a primary east–west route in Miami-Dade County. The current route endpoints on Kendall Drive are the Dadeland North Station (assigned MP 0) at the Kendall Drive intersection with the Snapper Creek Expressway, and the West Kendall Transit Terminal (assigned MP 8.729) at the Kendall Drive intersection with SW 162 Avenue, as shown in Figure 6-1. The total length for the bus route is approximately 8.729 miles. The segment of Kendall Drive selected in this study for examination of the developed methodology was from SW 107th Avenue (MP 3.2) to SW 147th Avenue (MP 8.787). There are 16 signalized intersections and 10 bus stops in each direction. Table 6-1, Table 6-2, and Figure 6-1 show the signalized intersections and bus route locations along the study area of Kendall Drive.

The Kendall Drive AVL data received from MDT through XML data stream is described in Chapter 3. The data includes bus position, direction, and time stamp.

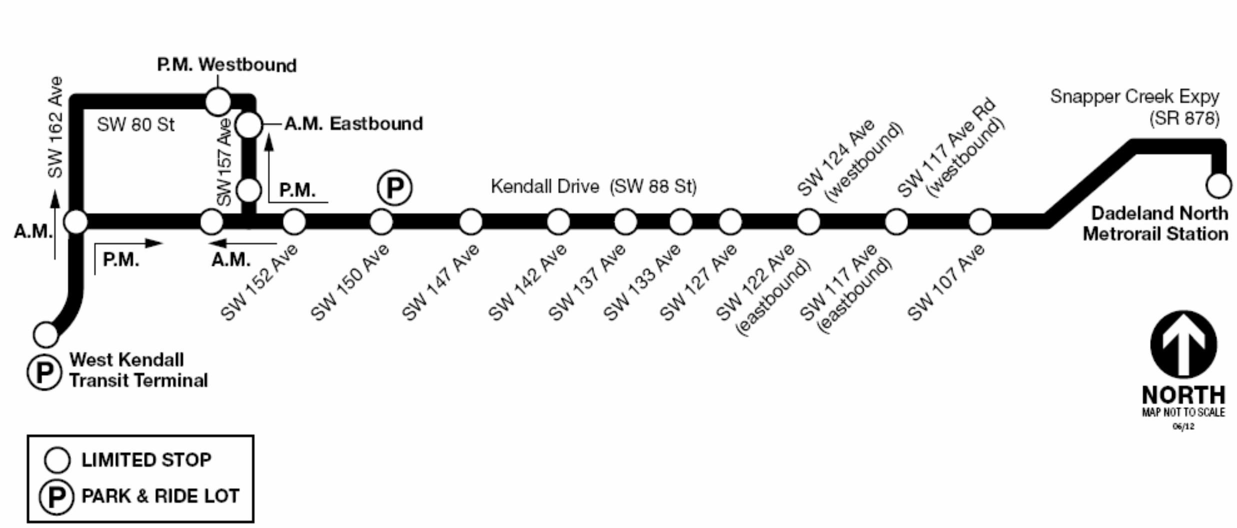


Figure 6-1 Kendall Cruiser Bus Route (288)

Table 6-1 Signalized Intersections along the Study Area

Intersections	Milepost
SW 152 Avenue	8.452
SW 150 Avenue	8.200
SW 147 Avenue	7.948
SW 142 Avenue	7.756
SW 137 Avenue	7.440
SW 133 Avenue	7.185
SW 130 Avenue	6.921
SW 127 Avenue	6.433
SW 125 Avenue	6.123
SW 124 Avenue	5.934
Mills Drive	5.011
SW 117 Avenue	4.933
Marion Road	4.765
SW 112 Avenue	4.427
SW 107 Avenue	3.763
SW 99 Court	3.064

Table 6-2 Bus Stop Locations along the Study Area

East Bound		West Bound	
Bus Stops	**Mile Post**	**Bus Stops**	**Mile Post**
SW 152 Avenue	8.361	SW 152 Avenue	3.783
SW 150 Avenue	8.225	SW 150 Avenue	4.951
SW 147 Avenue	7.773	SW 147 Avenue	5.534
SW 142 Avenue	7.411	SW 142 Avenue	5.982
SW 137 Avenue	6.987	SW 137 Avenue	6.451
SW 133 Avenue	6.455	SW 133 Avenue	6.964
SW 127 Avenue	5.903	SW 127 Avenue	7.465
SW 122 Avenue	5.542	SW 124 Avenue	7.787
SW 117 Avenue	4.959	SW 117 Avenue	8.184
SW 107 Avenue	3.780	SW 107 Avenue	8.401

6.3 Estimating General Traffic Travel Times

The data described in the previous section was used to estimate the bus travel times for individual links defined as the segments that connect bus stops on the test section. This section describes a methodology to estimate general traffic travel time based on bus travel time.

6.3.1 Determining Bus Stop Influence Areas

The first step to estimate the travel time of general traffic from the bus trajectory is to determine the influence areas of bus stops and adjust the travel times to account for the fact that buses stop at these locations, while other vehicles do not. The bus stop influence areas are defined as the areas of bus deceleration, stop, and acceleration in the road segment close to the bus stops as determined from bus trajectories. Identifying the impacts of the influence areas of each bus stop on bus travel times allows for the removal of these impacts from travel time measurements when estimating the travel time of general traffic.

In order to identify the impacts of the influence areas, time-space graphs were generated to plot the trajectories of different buses from multiple days for both the eastbound and westbound directions. The exact locations of the bus stops and intersections were also added to the graph to help identify the locations of the influence areas of the bus stops. Figure 6-2 shows an example of how the influence area can be determined using this method, from the trajectories of four different buses. Figure 6-3 shows examples of the influence area.

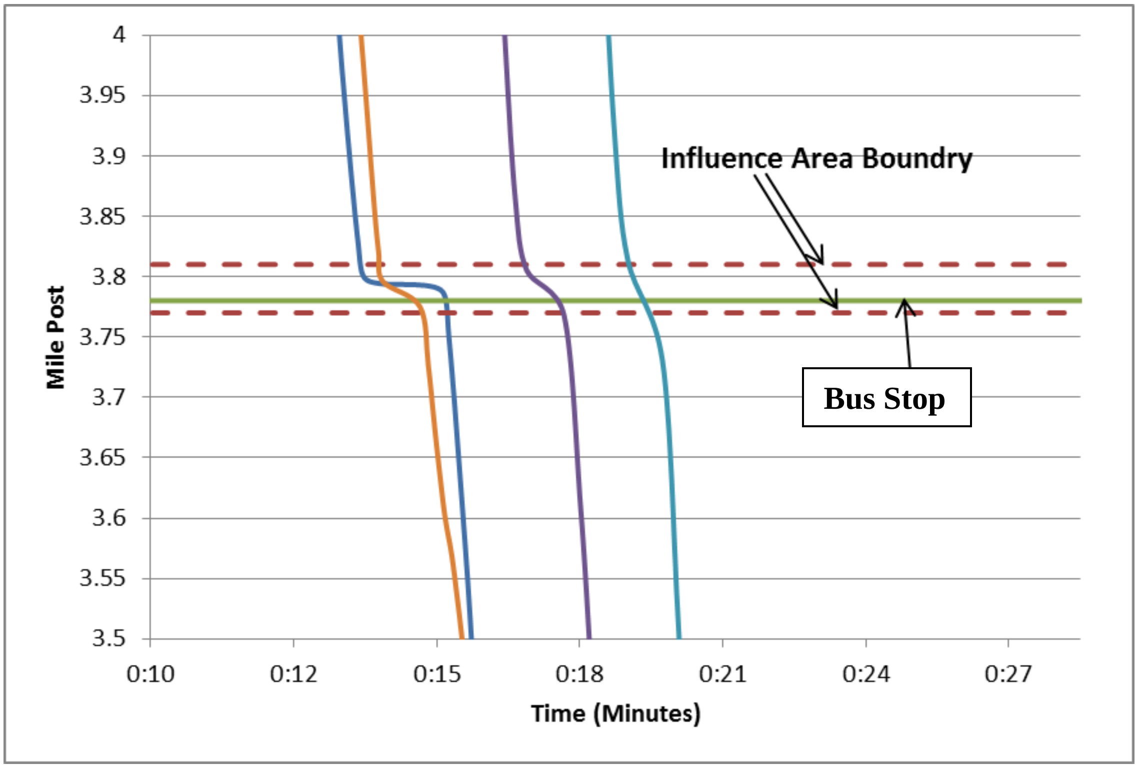


Figure 6-2 Example of Identifying the Influence Area based on Vehicle Trajectories

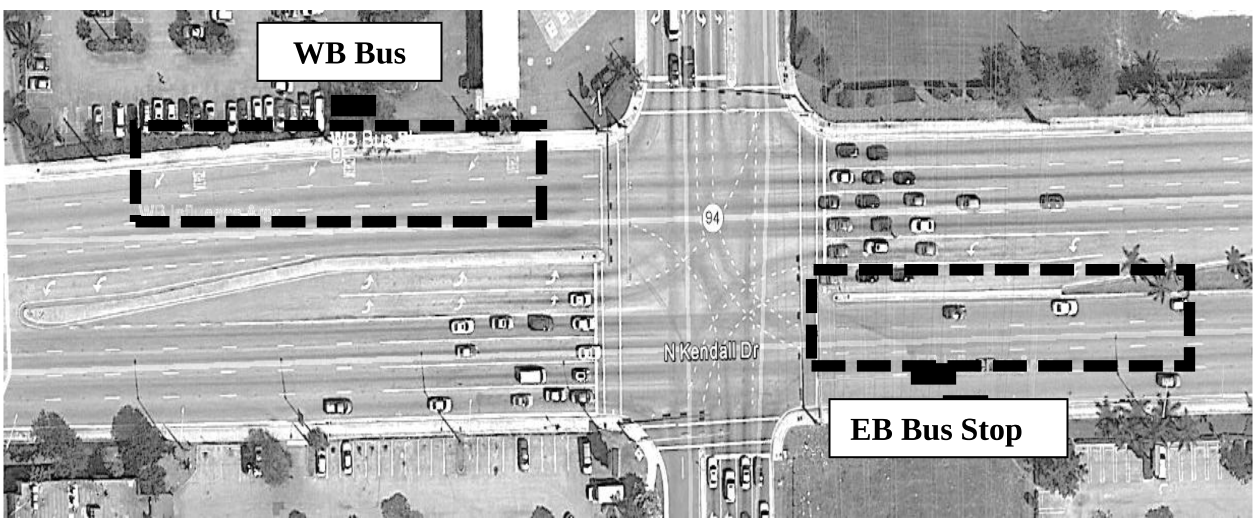


Figure 6-3 Examples of Influence Areas

6.3.2 Accounting for the Impact of the Influence Area

The bus travel time includes dwell deceleration, and acceleration times at the influence area. The next step is to isolate the impacts of the influence areas on the bus travel time to enable the calculation of general traffic travel times; Figure 6-4 illustrates this procedure. First, the travel time of the bus in the influence area is subtracted from the bus travel time. Next, the speed in the influence area without a bus stop is estimated by interpolating between the speeds of upstream and downstream links. Finally, a new trajectory and travel time for the bus are computed, assuming that the bus does not stop at the bus stop. The resulting trajectories and travel times are used in the next steps to estimate the travel times of general traffic. Based on above calculations, Figure 6-5 shows the time-space plot for bus and passenger car trajectories in the westbound direction of the study segment between 5:00 PM and 5:30 PM.

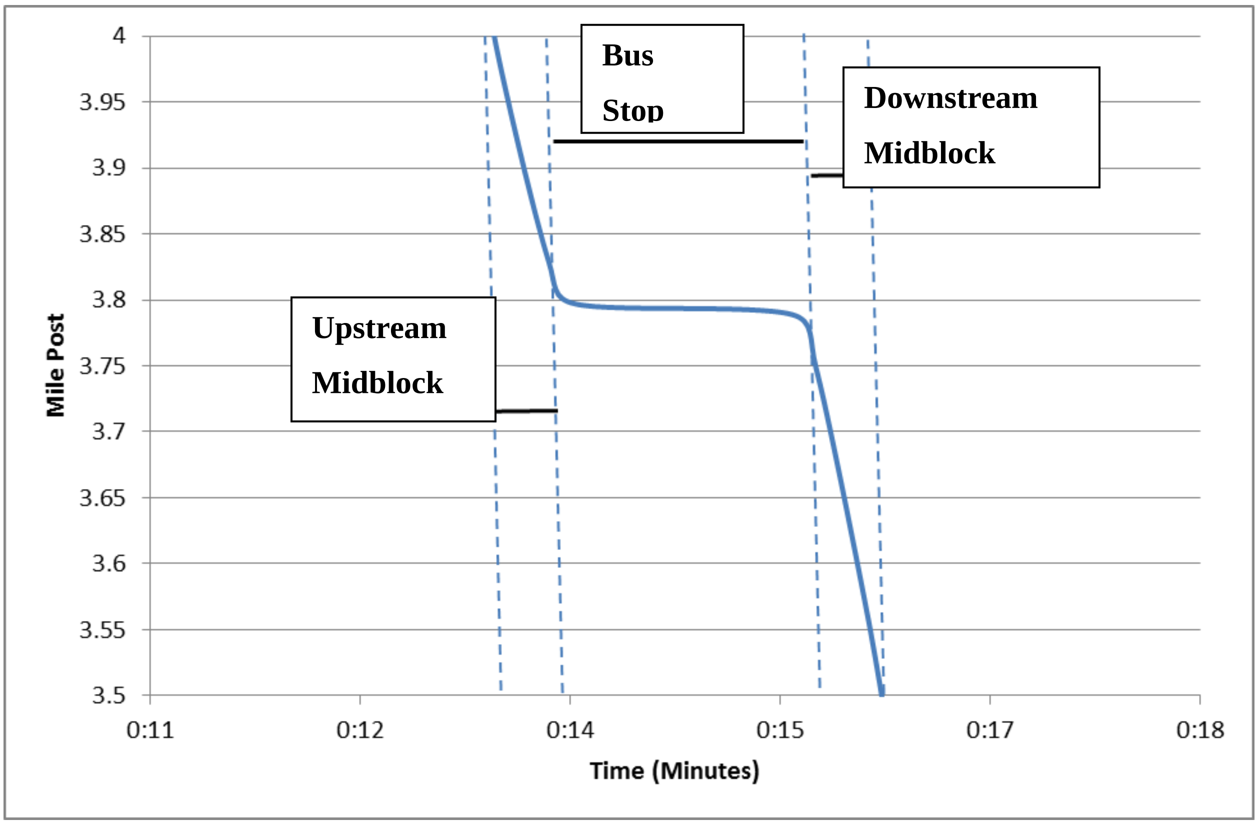


Figure 6-4 Travel Time Segments

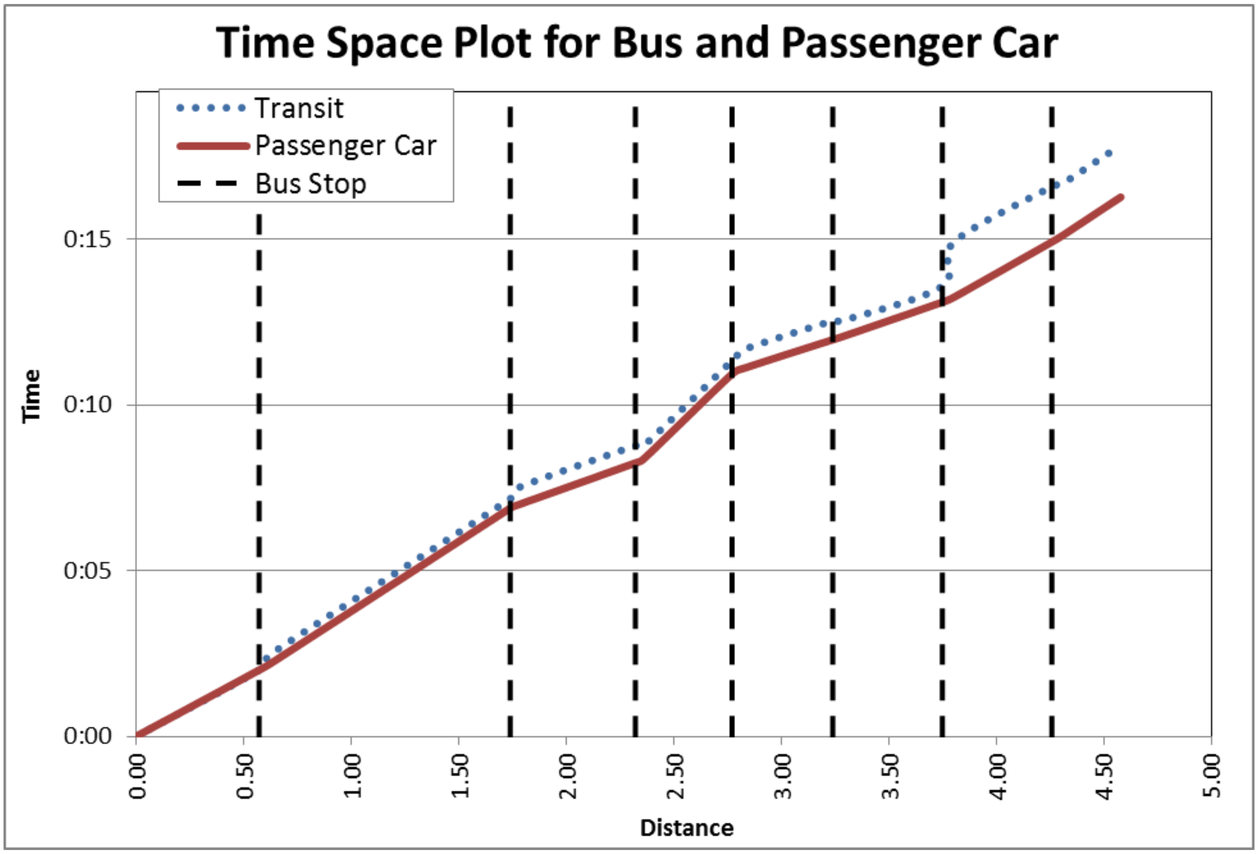


Figure 6-5 Time-Space Plot for Bus and Passenger Car

The methodology described above was used to estimate the travel time for bus and passenger cars (general traffic) in April 2011, for the time period between 5:00 and 5:30 PM, in the westbound direction. The average and 95% bounds of travel times are presented in Figure 6-6 for buses, and Figure 6-7 for passenger cars.

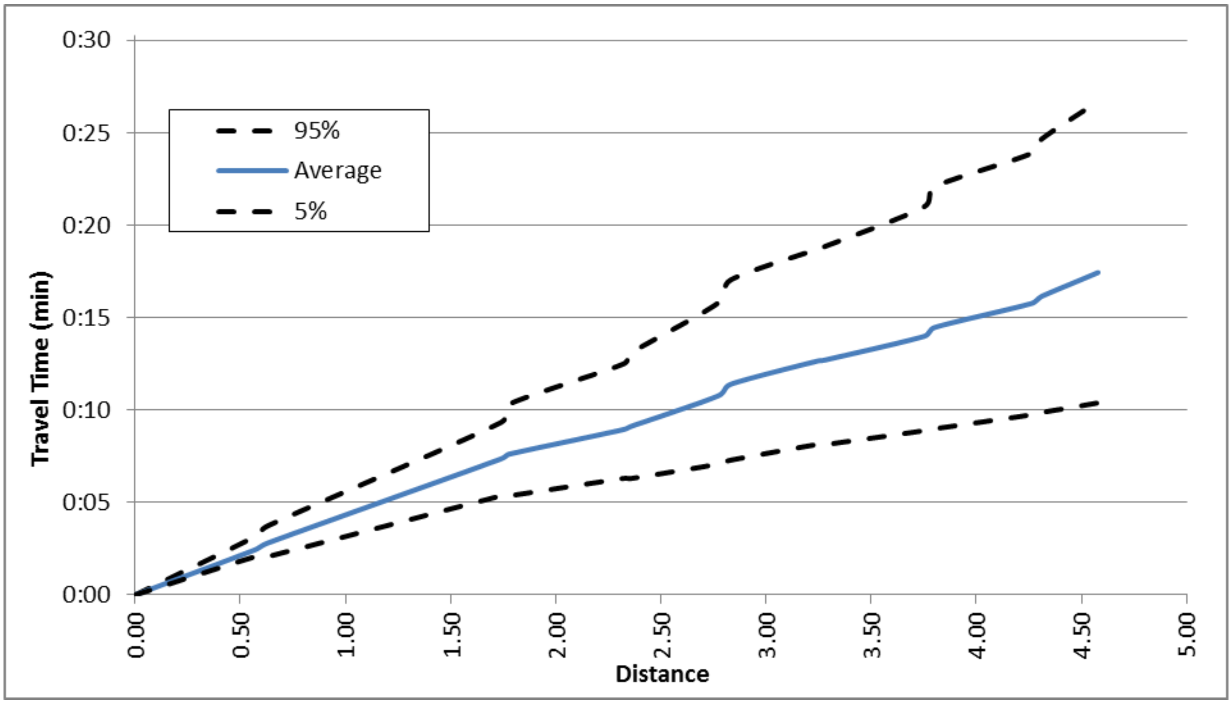


Figure 6-6 Average, 95% and 5% Travel Time for Buses between 5:00 and 5:30 PM in the Westbound Direction

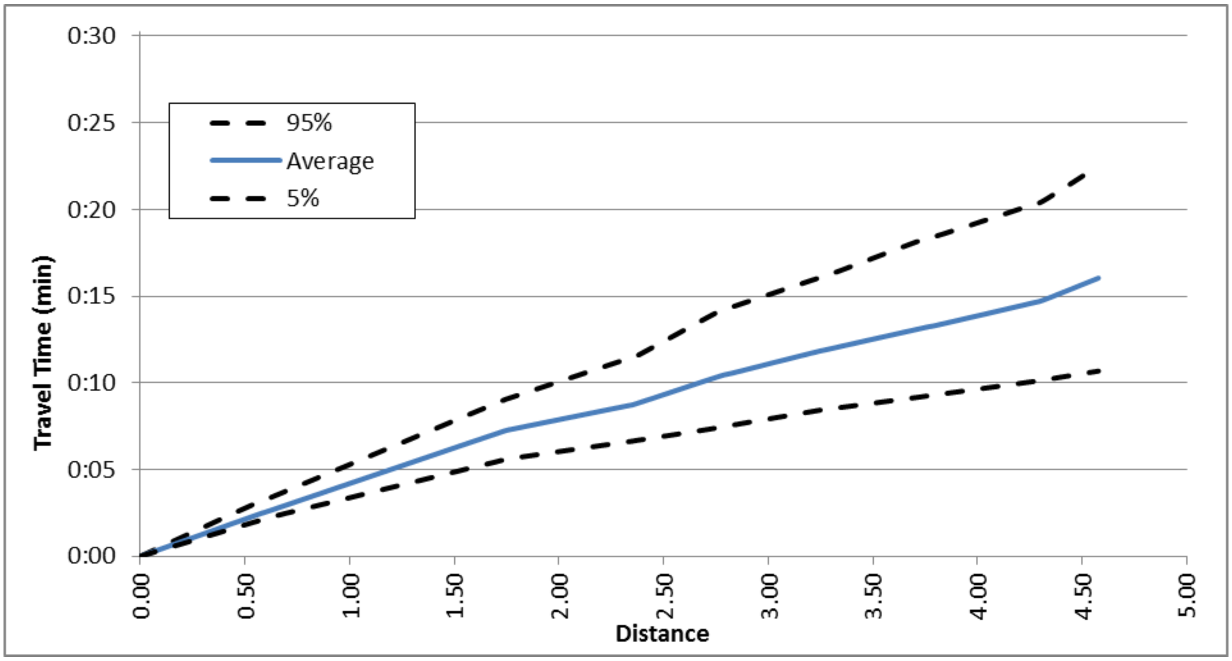


Figure 6-7 Average, 95% and 5% Travel Time for Passenger Cars between 5:00 and 5:30 PM in the Westbound Direction

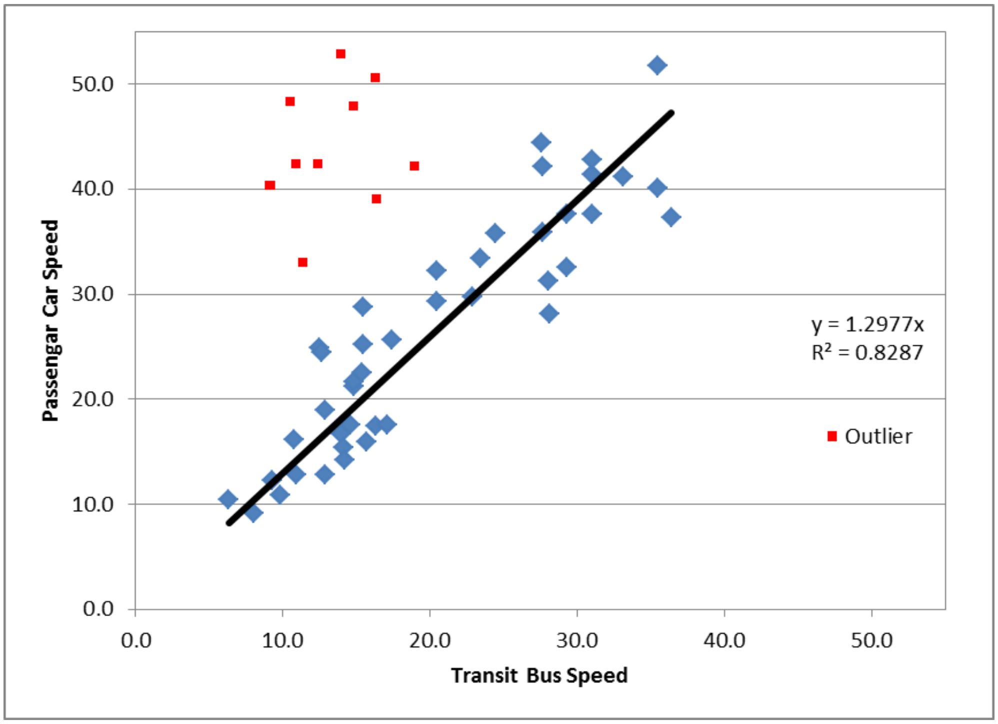
6.3.3 Accounting for the Difference between Bus and Passenger Car Performance

The analysis presented in Section 6.3.2 allows the subtraction of the impacts of the influence area of bus stops on travel times. However, further effort is needed to account for the difference between the operations of passenger cars and buses outside the influence areas. Previous studies confirmed that there are differences in travel time between buses and passenger cars at midblock and intersection locations. This study estimates these differences by conducting test car studies at the same times that the bus is in operation and building a relationship between the bus and passenger car travel times using regression analysis based on the collected data.

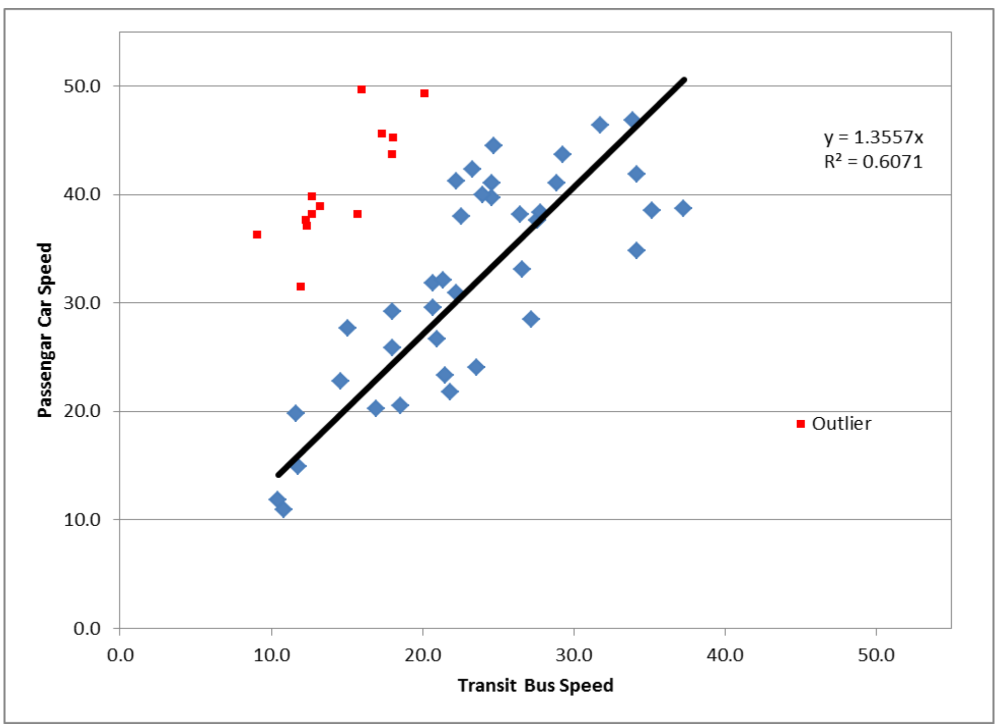
The test car studies were done for the selected segments in the AM peak and the PM peak for three days (November 15, 16 and 19). The floating car technique was used in this study with the test drivers instructed to drive at the average speed of the traffic stream. Each test vehicle was equipped with a GPS Receiver with a USB interface utilized to connect the receiver to a laptop computer. The collected travel time data from the test car method was analyzed using the PC-Travel software.

The test car runs started at the same times as a Kendall Cruiser bus equipped with AVL. The test car and bus travel times were collected and compared for the segments connecting the bus stops. The relationship between the bus and test car travel times was established using linear regression analysis for the westbound direction of the selected segment. The results of regression analysis are depicted in Figure 6-8 Relationship between the Speeds of Buses and Test Cars for the Segments that Connect the Influence Area

. Outliers for regression are also shown in red points in the figure.



(a) WB



(b) EB

Figure 6-8 Relationship between the Speeds of Buses and Test Cars for the Segments that Connect the Influence Area

The results of the regression analysis for westbound and eastbound are presented in Equation 6-1 and 6-2.

$$V_{PC} = 1.2997 * V_{Bus} \quad (6\text{-}1)$$

$$V_{PC} = 1.3557 * V_{Bus} \quad (6\text{-}2)$$

Figure 6-9 Example of the Trajectories of a Bus and Passenger Car shows a comparison between the trajectory of passenger cars (based on the test car studies), buses, and buses with the exclusion of the influence areas (based on the actual trajectories of buses).

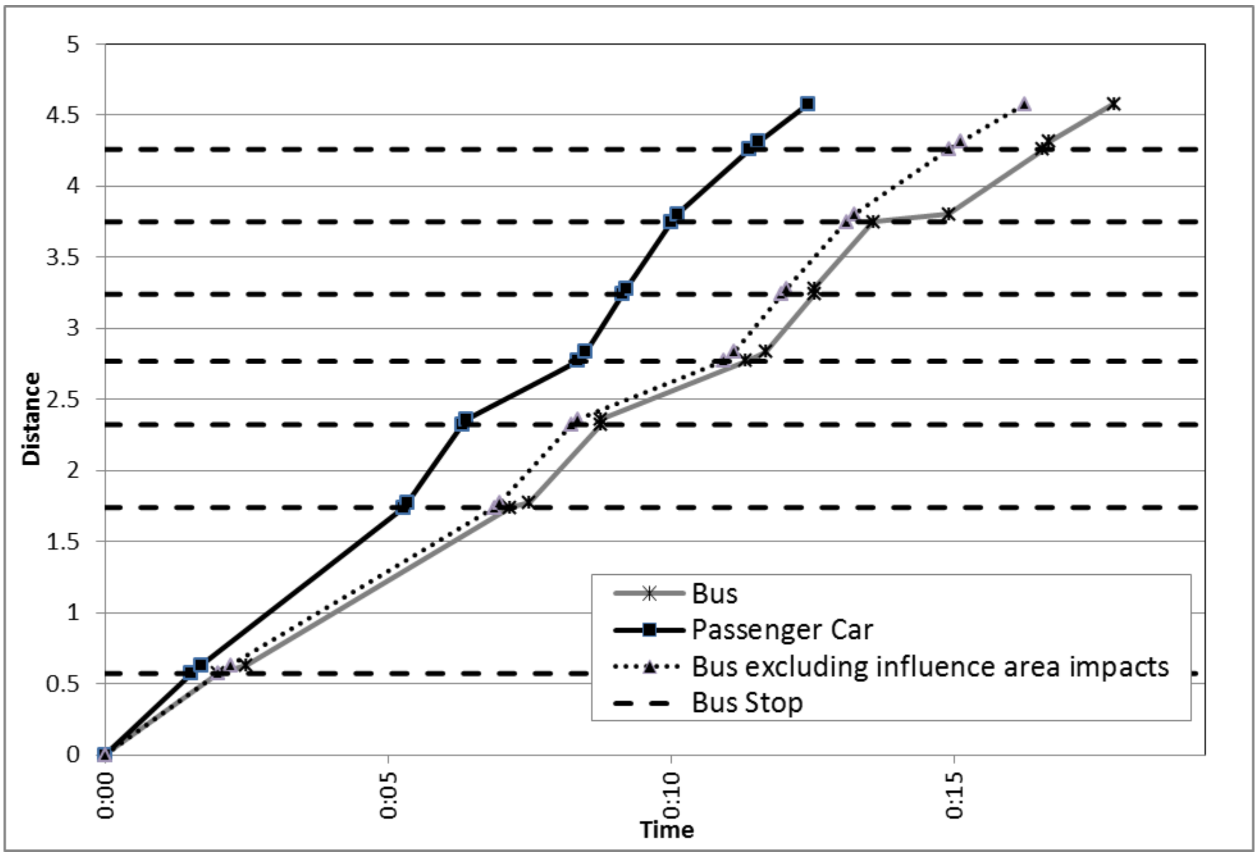


Figure 6-9 Example of the Trajectories of a Bus and Passenger Car

6.4 Utilization of the Estimate Travel Time

The travel times collected as described in the previous sections can be used for both off-line analysis of traffic operations and real-time operations. For off-line applications, the estimated travel times can provide another source of data for traffic analysis, potentially used instead of test car studies or data from other measurement sources.

For real-time applications, the travel times are displayed in real time on the IRISDS displays to regional transportation agencies showing current travel times and the deviations from the expected travel times based on historical displays. For further discussion of the real-time displays of IRISDS, please refer to Chapter 3 of this report.

6.5 References

1. Dailey, D. J., Maclean, S. D., Cathey, F. W., and Wall, Z. R. (2001). "Transit Vehicle Arrival Prediction: Algorithm and Large-Scale Implementation," Transportation Research Record: Journal of the Transportation Research Board, Vol. 1771, pp. 46-51, 2001.

2. Pu, W. and Lin, J. (2009). "Real-time Estimation of Urban Street Segment Travel Time Using Buses as Speed Probes." In the 88th Annual Meeting CD of Transportation Research Board, Washington, DC, 2009.

3. Pu, W. and Lin, J. (2010). Use of Real-time Bus Tracker Data for Urban Street Travel Time Estimation, Submitted to Transportation Research Part C (Under Review).

Appendix A Notes from Stakeholder Meetings

ICM and Advanced Technologies for Florida

MDT Meeting Notes September 3, 2010

Attendees

- Rosie Perez (MDT)
- Susanna Guzman-Arean (MDT)
- Monica Cejas (MDT)
- Mohammed Hadi (FIU)
- Chengjun Zhan (FIU)
- Albert A. Hernandez (MDT)
- Robert Pearsall (MDT)
- Hector Garnica (MDT)
- Fabian Cevallos (FIU)
- Jianguo Li (FIU)

Major Topics

The meeting is set up to discuss the scope of the project and the coordination among different agencies. The project will focus on ICM and Intellidrive concepts. The Intellidrive concepts may be implemented piece by piece, component by component, and serve as supplements to the ICM concepts. The project will be conducted using the following five steps: 1) Literature review. The USDOT has identified eight corridors for ICM and chosen three of them for implementation. The Florida International University (FIU) research team will evaluate the final reports and combine them with Florida's requirements to better serve the state's needs; 2) Project requirement. FIU will organize a workshop for the requirements and involve multiple stakeholders and agencies to make sure concerns from different parties are taken care of; 3) Modeling ICM strategies using simulation, especially in case of incident and/or construction work and/or bus usage in case of incident, etc; 4) Assessment. A corridor should be selected for field implementation as a proof of concept; and 5) Field evaluation.

Candidate Corridors

Criteria or parameters may need to be determined for candidate corridor selection. Possible parameters are the availability of multimodal and route alternatives, type of signal controllers, communication systems availability, etc. The following corridors may be good candidates, according to MDT: 1) East-West corridor, which will be implemented in 2014; 2) North corridor, phase I set to be in 2012; 3) 7^{th} Avenue, parallel to I-95; 4) Dolphin Expressway: Since this corridor is under construction, it may serve as a special case for work zone management strategy evaluation; 5) Palmetto Expressway: The corridor will implement HOV lane/Managed lane in the future; 6) Biscayne Boulevard; 7) I-75; 8) NW 27^{th} Avenue, which can serve as an alternative to I-95 and the Florida Turnpike, and if it is chosen, we can also model NW 7^{th} Avenue. During the discussion, US-1 was eliminated as a candidate by MDT because it is currently being studied by MDX for converting the bus lane to managed lane. It appears that NW 27^{th} Avenue with its proposed Bus Rapid Transit (BRT) is a good alternative.

Discussions

1. Transit schedule change during incidents: This task is challenging but possible.
2. Information sharing: MDT is very interested in this and has just started receiving information from MDX.
3. Bus priority: A pilot project is initiated on Kendall Drive. MDT will evaluate the effectiveness and automate the process in the future. Regarding this issue, Miami Public Works Group wants more detailed information about bus operations (schedule, ridership, real-time location information, on schedule or delay, turning movements, etc.), and MDT is willing to share the information. One limitation is the latency with the current wireless communication system to the buses. Miami-Dade County will start deploying a hybrid cell/Wi-Fi network for their signal control starting where needed. MDT could use this information to get more information at more frequent time intervals from the buses. Miami Public Works Group wants 1-second data on bus locations, and MDT said it currently could only provide 6-7 seconds information updates; it is difficult to provide less than 3-second data due to the current frequency capacity.

4. Construction maintenance: Currently, information sharing is very minimal and MDT wants real-time information and schedules of construction maintenance work and real-time from FDOT/MDX/Miami-Dade County. May include local municipalities.
5. Signal failures: Considered not very important by MDT.
6. Cooperation with port: Not very critical to MDT, may be important for freight management.
7. Park and ride: Should be combined with traveler information system.

Miscellaneous

1. Real-time information system, such as next-bus, could be important to this effort.
2. Coordination with Miami Public Works Group: Need to know the details about the wireless project for traffic signals for areas without fiber-optic communications. The routers can support two protocols: cellular or Wi-Fi. This issue may be a major topic for the face-to-face requirement meeting for local agencies.
3. Camera feeds: Will be beneficial to MDT.
4. Need for survey of public opinions on using buses. However, this is beyond the scope of this study.

Miami-Dade Public Works Meeting Notes

September 2, 2010

Attendees

- Robert Williams (Public Works)
- Mohammed Hadi (FIU)
- Jeffrey Gropper (FIU)
- Chengjun Zhan (FIU)
- Jianguo Li (FIU)

Project Scope

The meeting was set up to discuss the scope of the project and the coordination among different agencies. The project will focus on ICM and Intellidrive concepts. The project will be conducted using the following five steps: 1) Literature review — The USDOT has identified eight corridors for ICM and chosen three of them for implementation. The FIU research team will evaluate the final reports and combine them with Florida's requirements to better serve the state's needs; 2) Project requirement — FIU will organize a workshop for the requirements and involve multiple stakeholders and agencies to make sure concerns from different parties are taken care of; 3) Modeling ICM strategies using simulation, especially in case of incident and/or construction work and/or bus usage in case of incident, etc.; 4) Assessment — A corridor should be selected for field implementation as a proof of concept; and 5) Field evaluation.

Candidate Corridors

Criteria or parameters may need to be determined for candidate corridor selection. The following corridors may be good candidates, according to Mr. Williams: 1) I-95, which is a good candidate for multimodal traffic systems; 2) US-1, which is in close proximity of the metro-rail; 3) Dolphin Expressway (however, there is a limited extra capacity on alternative routes); and 4) SR-112 combined with metro-rail and NW 36th Street (although this corridor is not very congested).

Discussion

1. Signal Control during Incidents: Various attempts have been made in the last 20 years to adjust the signal plans during incidents with no success. One issue is the time it takes to inform the county operators of the incident and its impacts. Also, each incident is different. Coming up with a library of timing plan is going to be difficult. It may be better to provide incident alarms and share the video with the operators and let the operator select the timing in real time. According to Mr. Williams, in the 1980s, the idea of special signal patterns for traffic diversion was implemented, but it was not successful. The main reasons were: 1) the incident management agencies never called the signal control group in case of incidents; and 2) even when the signal control group was called, not enough details were provided (percentage of diversion, severity, etc.) because traffic diversion was not a top priority issue. About five years ago (2005), FDOT proposed another initiative for special signal patterns in case of incidents.

2. Signal control-general: If there are backups from surface streets to the freeway, the county tries its best to reduce the queue. Adaptive control will be considered in the next phase of the signal system, which will be advertised shortly.

3. Emergency vehicle operations: Miami-Dade County prefers central and software-based emergency vehicle preemption and is currently implementing the preemption in this manner. Possible improvements to preemption operations for this project include providing exact locations of emergency vehicles (AVL or GPS) and the exact mode of emergency vehicles (emergency status/normal/special conditions, etc.). The signal control group has the ability to make signal preemption; it just needs the detailed information to make decisions.

4. Bus Priority: Need the transit agency to provide the signal control group, the schedule/status, immediate left-turn/right-turn movement information, number of passengers, schedule status. At the current stage, everything is done through radio communication and requires manual control. In the future, everything should be automated. For bus priority, the signal control group prefers centralized software control.

A project was implemented on Kendall Drive, and the main issue is that there is only marginal improvement of transit vehicles (5% improvement).

5. Traveler information: DMS is not capable of conveying enough information to travelers. Mr. Williams prefers diversion information disseminated through HAR/Cell Phone/Vehicle Dashboard, etc.

ICM and Advanced Technologies for Florida

MDX Meeting Notes

August 31, 2010

Attendees

- Ivan del Campo (MDX)
- Mohammed Hadi (FIU)
- Jeffrey Gropper (FIU)
- Angel Reanos (HNTB)
- Chengjun Zhan (FIU)
- Jianguo Li (FIU)

Major Topics

The meeting was set up to discuss the scope of the project and the coordination among different agencies. The project will focus on ICM and Intellidrive concepts. The project will be conducted using the following five steps: 1) Literature review. The. USDOT has identified eight corridors for ICM and chosen three of them for implementation. The FIU research team will evaluate the final reports and combine them with Florida's requirements to better serve the state's needs; 2) Project requirement. FIU will organize a workshop for the requirements and involve multiple stakeholders and agencies to make sure concerns from different parties are taken care of; 3) Modeling ICM strategies using simulation, especially in case of incident and/or construction work and/or bus usage, etc.; 4) Assessment. A corridor should be selected for field implementation as a proof of concept; and 5) Field evaluation.

Candidate Corridors

Criteria or parameters may need to be determined for candidate corridor selection. Possible parameters are the availability of multimodal and route alternatives, type of signal controllers, communication systems available, etc. The following corridors may be good candidates: 1) SR-836 from 137th Avenue to 37th Avenue — construction work is the major issue for this corridor in the coming years, and construction-related congestion should be modeled; 2) US-1, which has parallel bus lanes; 3) I-95, which has a managed lane and ramp meters — in addition, the bus lane on SR-7 and Tri-Rail are also in close proximity, which provides the opportunity for modeling different modes. Priority bus and regular bus may also be modeled if this corridor is chosen; and (4) SR-112 combined with NW 36th Street.

Discussion

1. Construction: Construction of SR-836 will have significant effects; it will be important to know the impacts and solutions.
2. Transit: MDT has requested access to MDX data (camera, sensors, etc). MDT seems very interested in getting these for use in their operations. MDX is currently sending email alerts of incidents using SunGuide, and this can be provided for MDT. MDX is considering allowing the access of the SunGuide software/GIS layer by MDT. It should be mentioned that MDT is operating a bus on the shoulder of SR-874.
3. Incident management: Sharing information with emergency agency is important for effective incident management. When incidents occur on freeways or arterials, what are the optimal routes for emergency vehicles and buses.
4. Off-ramps backed up from arterials: One good example is the 87th Avenue exit for SR-836 (EB), which is peaked in the morning.
5. Stakeholders: Improvement of operations, such as fire truck dispatch based on traffic data and signal preemption, and the coordination with police, fire truck, and/or port operations.

Miscellaneous

1. Additional issues: the way information is conveyed (511/DMS/text messaging, etc.), which may be evaluated as part of the evaluation tool project? What will be more useful to people?
2. Miami-Dade downtown parking management system: Integration in case of events.

3. Construction & maintenance on alternative routes: coordination among agencies.
4. Data archiving: ITS device deployment.