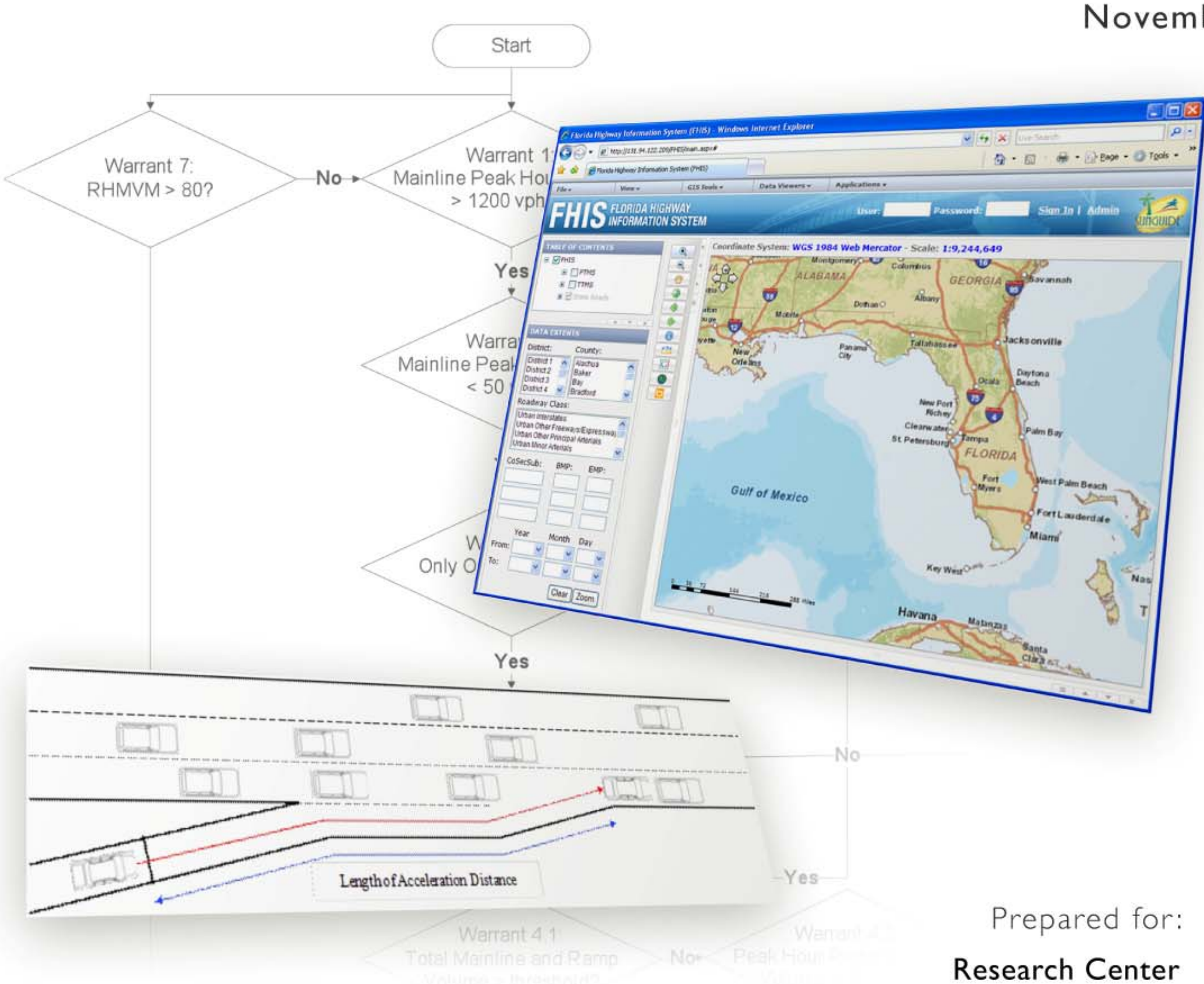
Integrated Database and Analysis System for the Evaluation of Freeway Corridors for Potential Ramp Signaling

Final Report

Contract No. BDK80 TWO 977-08

November 2011



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Florida Department of Transportation

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In collaboration with:
AECOM Technical Services, Inc.

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November 2011

DISCLAIMER

METRIC CONVERSION CHART

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
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
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
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
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
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

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Mr. Javier Rodriguez, P.E., ITS Freeway Operations Engineer with the District 6 Florida Department of Transportation, served as the project manager for this study.

16. Abstract

Ramp signaling is a relatively low-cost traffic management strategy that aims to improve the flow of traffic by controlling the rate at which vehicles enter the freeway. While studies have shown that ramp signaling helps to alleviate traffic congestion and improve traffic safety, not all freeway locations are suitable for ramp signaling. Guidelines are needed to help determine the suitability of freeway locations for ramp signaling. Proper evaluation of potential locations in accord with these guidelines requires the use of data sets currently maintained separately by various FDOT offices. This project identified and evaluated the existing ramp signaling guidelines from 12 states in the U.S., four other countries, and three independent research organizations. It then selected a set of guidelines for Florida applications considering the availability of data for evaluation and the experiences gained from the Interstate 95 ramp signaling project in Miami-Dade County, Florida. A web-based Geographic Information System (GIS) was then developed to automate, to the extent possible, the process of evaluating sites for potential ramp signaling on the basis of the selected guidelines. A major component of the system is a central database that integrates five independent data sets from FDOT, including roadway inventory, detector data (including volume, speed, and occupancy), traffic counts, police crash records, and SunGuide incident records. The system greatly reduces the data acquisition effort, which is often the most time-consuming part of a project. The system can also be used as a tool for general data retrieval and serve as a platform for other applications. Several enhancements were recommended to further improve the system, including adding more data with additional details and additional visualization and reporting functions.

17. Key Word	18. Distribution Statement
Ramp Signaling, Ramp Metering, Warrants, GIS, Data Integration	

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EXECUTIVE SUMMARY

Ramp signaling is a traffic management strategy that installs traffic signals at freeway on-ramps to regulate the flow of traffic onto the freeway mainline. While studies have shown that ramp signaling helps alleviate traffic congestion and improve traffic safety, not all freeway facilities can benefit from ramp signal installation without incurring other problems such as excessive negative impacts on local arterials. Guidelines are thus needed to help transportation engineers and planners determine the suitability of specific corridors for ramp signaling. Proper evaluation of potential sites in accord with these guidelines requires the use of data sets currently maintained separately by various Florida Department of Transportation (FDOT) offices. The objectives of this study are thus to review existing ramp signal guidelines, evaluate and select those considered to be suitable for Florida's use, and then develop a computer system that applies these guidelines to assess the suitability of a select freeway location for ramp signaling.

To gain a good understanding of the current status of development for ramp signaling guidelines, the research team conducted an extensive review of the existing guidelines used for justification of ramp signaling. The literature includes guidelines from 12 states in the U.S., four other countries, and three independent research organizations. Some of the key findings of this effort include:

1. There are very few published or formalized "warrants" that can be directly used for ramp signaling,
2. Development of a set of ramp signaling warrants is challenging because of the influence of multiple factors,
3. The existing individual warrants are both qualitative and quantitative, and
4. A systematic methodology is preferred when a set of individual warrants are available.

Five criteria were established to guide the evaluation and recommendation of individual guidelines. This is to ensure that the potential guidelines are not only appropriate, but also objective and can potentially be automated in a computer system. This study also compared similar criteria used by different agencies but with varying threshold values and conditions. To assess their effectiveness, several guidelines were applied to the existing ramp signaling sites on Interstate 95 in Miami-Dade County, Florida.

Based on the evaluation, seven guidelines were recommended for incorporation into the proposed system. These guidelines are grouped into three general categories in the form of warrants: traffic (warrants 1, 2, 3, and 4), geometric (warrants 5 and 6), and safety (warrant 7). Specifically, these warrants include:

1. Mainline peak hour volume > 1,200 vphpl.
2. Mainline peak hour speed < 50 mph.
3. For one-lane ramp, peak hour ramp volume is between 240 vph and 1,200 vph; and for multilane ramp, peak hour ramp volume is between 400 vph and 1,700 vph.
4. Total mainline volume and ramp volume is greater than the minimum threshold (depending on number of lanes) or the peak hour rightmost lane volume is greater than 2,050 vph.

5. Ramp storage distance is greater than the minimum requirement determined by the peak hour ramp volume.
6. Acceleration distance is greater than the minimum requirement determined by the freeway mainline prevailing speed.
7. Crash rate is greater than 80 per hundred million vehicle-miles.

Recognizing that each individual warrants may have different priority in justifying ramp signaling, a systematic procedure (in the form of a flow chart) is recommended.

After the guidelines in the form of warrants were selected, a web-based Geographic Information System (GIS), called the Florida Highway Information System (FHIS), was developed to automate, to the extent possible, the process of evaluating freeway sites for potential ramp signaling based on the selected guidelines. A major component of the system was a central database that integrates five independent data sets from different FDOT offices. The data sets included roadway inventory, detector data (including volume, speed, and occupancy), traffic counts, police crash records, and SunGuide incident records. The development of the web-based system greatly reduces the data acquisition effort, which is often the most time-consuming part of a project. The system can also be used as a tool for general data retrieval and serve as a general platform for implementing other potential applications.

The web-based GIS system has successfully combined the different data sources in an integrated database, implemented the functions for ramp signaling evaluation based on the selected guidelines, and provided functions for quick data retrieval and visualization. Further enhancements to the system could include adding (1) more data for additional details such as detector data in smaller time intervals (e.g., 15-minute), (2) additional visualization functions such as displaying crash locations on GIS maps, and (3) reporting functions that allow more flexible selection of variables that may come from multiple data tables.

Because the geometric data for ramp length and acceleration lane length are not directly available from FDOT's Roadway Characteristics Inventory (RCI), warrants 5 and 6 as described above have not been implemented in this initial version of the system. These data may, however, be acquired through development of a combination of automated tools and manual processing, thus, making the evaluation of warrants 5 and 6 possible within the system.

Another enhancement to FHIS will be to work with the University of Florida (UF) researchers to access the STEWARD detector database directly. In this project, a tool was developed to automatically access the STEWARD data and integrate them into the FHIS system. This process, while proven to be feasible, is both slow and subject to server and network instability as well as changes to the STEWARD system made by UF. The direct data access option will avoid data duplication and save storage space on the local FHIS server. This is significant considering the large amount of detector data involved. The direct data access option will also allow FHIS to make use of the most current detector data available in STEWARD, with no data lead time.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1. Background

Ramp signaling (or metering) is a traffic management strategy that installs ramp signals at freeway on-ramps to regulate the flow of traffic onto the freeway mainline. The primary objectives of ramp signals include (Balke et al., 2009):

- controlling the number of vehicles entering the freeway,
- reducing freeway demand, and
- breaking up the platoons of vehicles released from upstream traffic signals.

When activated, a ramp signal alternates between green and red to vehicles entering the freeway and allows them to smoothly merge onto the mainline traffic. In this way, turbulence and delay that may be caused by a platoon of vehicles competing for the available gaps can be minimized. Although some queuing may be observed on the on-ramp, ramp signals have been shown to be able to optimize mainline flow, and thus improve the overall traffic flow on the corridor. Figure 1-1 shows a ramp signal implemented by the Florida Department of Transportation (FDOT) District 6 on Interstate 95 in Miami-Dade County, Florida.

Figure 1-1 A Ramp Signal Implemented by FDOT

Since the 1960s, ramp signaling has been implemented in metropolitan areas across the United States (U.S.). Table 1-1 lists the 23 metropolitan areas in the U.S. that have deployed ramp signals, along with the percentage of ramps implemented in each. Ramp signaling has also been successfully implemented in other countries, including the United Kingdom, Netherlands, Australia, New Zealand, South Africa, etc.

Table 1-1 Metropolitan Areas in the U.S. with Ramp Signaling

No.	Metropolitan Area	State	Number of Ramps		
			Metered	Total	Percent
1	Albuquerque	NM	2	100	2%
2	Allentown, Bethlehem, Easton	PA	14	58	24%
3	Atlanta	GA	8	980	1%
4	Chicago, Gary, Lake County	IL	113	1076	11%
5	Denver, Boulder	CO	54	200	27%
6	Fresno	CA	47	136	35%
7	Houston, Galveston, Brazoria	TX	89	656	14%
8	Janesville-Beloit	WI	56	NA	NA
9	Las Vegas	NV	3	128	2%
10	Los Angeles, Anaheim, Riverside	CA	2410	2410	100%
11	Miami, Fort Lauderdale	FL	22	560	4%
12	Milwaukee, Racine	WI	126	148	85%
13	Minneapolis, St. Paul	MN	416	416	100%
14	New York, Northern New Jersey, Southwestern Connecticut	NY	86	1850	5%
15	Philadelphia, Wilmington, Trenton	PA	16	688	2%
16	Phoenix	AZ	132	304	43%
17	Portland, Vancouver	OR	106	106	100%
18	Salt Lake City, Ogden	UT	32	160	20%
19	San Diego	CA	284	670	42%
20	Santa Barbara	CA	1	NA	NA
21	Seattle, Tacoma	WA	148	452	31%
22	St. Louis	MO	1	400	0%
23	Washington	DC	24	746	3%

In Florida, FDOT District 6 successfully launched its first ramp signaling system in the state in February 2009. The system included eight ramp signals along the northbound section of I-95 in Miami-Dade County. In April 2010, another 14 signals were deployed on northbound and southbound sections of the same corridor. Before-and-after studies based on both travel time runs and detector data have shown that the ramp signals significantly improved travel speeds and flow rates on the corridor (Gan and Wu, 2009; Gan and Wu, 2010). These results have garnered interest for ramp signaling from other agencies in Florida. For instance, District 4 is planning similar implementation on the I-95 section in Broward County and the Miami-Dade Expressway Authority (MDX) is also considering ramp signaling. Other districts including 2, 5, 7, and the Turnpike are expected to consider similar deployments as well.

1.2. Problem Statement

Despite their newfound popularity in Florida, ramp signals may not be beneficial for all freeway corridors. For example, corridors that do not provide for traffic diversion via alternate routes may not be suitable for ramp signaling, nor will those that experience serious bottlenecks due to geometric constraints. Accordingly, guidelines are needed to help transportation engineers and planners determine the suitability of specific corridors for ramp signaling. Proper evaluation of potential sites in accord with these guidelines requires the use of data sets currently maintained separately by various FDOT offices. There is a need for a system that combines these independent data sets into an integrated database and provides the tools needed to quickly access the database and perform data analysis. Such a system can help reduce especially the data acquisition effort, which is often the most time-consuming part of a project.

1.3. Project Objectives

The objectives of this project are thus twofold. The first objective is to review the existing ramp signal guidelines and then recommend those that are considered implementable and are deemed appropriate for Florida. In evaluating if a guideline is implementable, a major consideration will be the availability of the data required for evaluation.

The second objective of this project is to develop a system that is designed to automate, to the extent possible, the process of evaluating a freeway location for potential ramp signaling on the basis of the selected guidelines. A major component of the system is a central database that integrates several independent data sets from FDOT, including:

1. STEWARD (Statewide Transportation Engineering Warehouse for Achieved Regional Data) database, which provides volume, speed, and occupancy data from traffic detectors.
2. Roadway Characteristics Inventory (RCI), which provides roadway geometric data, including number of mainline lanes, number of ramp lanes, lane width, acceleration lane length, ramp length, speed limits, etc.
3. Florida Traffic Information (FTI), which provides mainline and ramp volumes.
4. Crash Analysis Reporting (CAR), which provides detailed traffic crash records.
5. SunGuide incident database, which provides freeway incident data.

1.4. Report Organization

The rest of this report is organized as follows. Chapter 2 provides additional details on the potential benefits of ramp signaling and summarizes the findings from an extensive review of the existing guidelines for ramp signaling. Chapter 3 presents the guidelines selected for Florida applications and provides justifications and reasoning for the selection. The guidelines were selected through a comprehensive evaluation of existing guidelines, supplemented with experience from FDOT District 6's ramp signaling project. Chapter 4 describes the architecture of a web-based Geographic Information System (GIS) designed to automate the process of evaluating the potential freeway locations for ramp signaling. The central database supporting the GIS application is introduced in detail. Chapter 5 introduces the user interface of the system and the associated functions. The final chapter provides a summary of this project and recommends potential enhancements to the system.

CHAPTER 2
EXISTING RAMP SIGNALING GUIDELINES

This chapter reviews existing guidelines (in the form of warrants and criteria) for justification of ramp signal installation. The scope includes those in the U.S. as well as several countries outside the U.S. Both qualitative and quantitative guidelines are reviewed. The results from this review provide a basis for further evaluation and recommendation of ramp signaling guidelines for Florida applications. A brief introduction to ramp signal strategies and a more detailed illustration of their benefits are first given.

2.1. Ramp Signal Strategies

Depending on the strategies used for controlling the flow of vehicles entering freeway facilities, there are three general types of ramp signal implementations (Jacobson et al., 2006):

- *One Vehicle per Green Metering (Single-Lane):* It permits vehicles to enter the freeway one-by-one, as vehicles approach the signal. One vehicle per green metering has a capacity of 900 vehicles per hour (vph). If a capacity greater than 900 vph is desired, a multiple vehicle per green approach may be suitable.

- *Multiple Vehicles per Green Metering (Single-Lane):* This approach, also known as platoon or bulk metering, allows two or more vehicles to enter the freeway facility per green cycle. Typically two, and in some cases three, vehicles are permitted to pass the ramp meter during each green signal indication. Compared to the one vehicle per green approach, the multiple vehicle per green approach results, on average, in an increase in throughput of about 200 to 400 vph.

- *Tandem or Two-Abreast Metering (Dual-Lane):* It permits two or more vehicles to enter the freeway facility per cycle, depending on the number of lanes at the meter (one vehicle per lane). To smoothen the flow of vehicles merging with freeway traffic, vehicles in each lane are released in a staggered fashion. Tandem metering may be combined with multiple vehicles per green in some locations where demand is extremely heavy.

The characteristics of these three types of ramp signaling strategies are listed in Table 2-1.

Table 2-1 Characteristics of Ramp Signaling

Ramp Signaling Type	Number of Lanes	Cycle Length (seconds)	Range of Metering Rate (vph)	Capacity (vph)
One Vehicle per Green	1	4 - 4.5	240 - 900	900
Multiple Vehicles per Green	1	6 - 6.5	240 - 1,200	1,100 - 1,200
Tandem	2	-	400 - 1,700	1,600 -1,700

2.2. Benefits of Ramp Signaling

When properly installed, ramp signals have the potential to accrue benefits from multiple perspectives, including safety, traffic operations, and environment.

2.2.1. Safety

A major potential benefit of ramp signaling is increase in safety, primarily through reduction in the number of crashes in acceleration lanes and merging areas. Nationally, it was found that ramp metering can reduce crash frequency by 15% to 50% (Arnold, 1998). Henry and Mehyar (1989) reported that, in Seattle, ramp metering reduced the number of accidents by 20% to 58%. Minnesota also reported that ramp metering reduced the crash rate by 24% (Cambridge Systematics, Inc., 2002).

2.2.2. Traffic Operations

Another major benefit of ramp signaling is improvement in overall traffic operations. Several of these improvements are described below.

- *Increase in Travel Speeds:* A survey of seven ramp signaling systems in the U.S. and Canada revealed that average highway speeds increased by 29% after ramp signaling was installed (Myers, 1997). In 2009 and 2010, the floating car studies performed by Florida International University (FIU) on I-95 in Miami-Dade County showed that ramp signaling increased travel speeds on northbound and southbound by 45% and 11%, respectively (Gan and Wu, 2009; Gan and Wu, 2010).

- *Improvements to Travel Time Reliability:* Although no literature that quantifies the effects of ramp signaling on travel time reliability was found, a study performed by Cambridge Systematics (2002) for the Minnesota Department of Transportation showed that freeway travel time without ramp signaling was twice as unpredictable as with ramp metering.

- *Increase in Vehicle Throughput:* Ramp signaling controls traffic demand such that the mainline capacity is not exceeded, maintaining a continuous traffic flow. Therefore, ramp signaling has the potential to increase freeway throughput. Similar results were documented by several previous studies. In Seattle, a 12% to 14% increase in freeway throughput was observed after ramp metering (Arnold, 1998). A study done by Cambridge Systematics (2001) found that the freeway mainline throughput during peak period declined by an average of 14% when ramp meters were turned off.

- *Promotion of Freeway Use for Long Trips:* Ramp signaling could improve the corridor's overall traffic operations by promoting freeway usage for long trips. Ramp signaling tends to divert short trips to underutilized local streets while reserving the freeway for longer trips, which is considered to be desirable in terms of the existing resource allocation priorities.

2.2.3 Environment

Ramp signaling can increase travel speed and relieve congestion by reducing stop-and-go conditions on the freeway, and hence has the potential to reduce fuel consumption and emissions.

- *Reduction in Fuel Consumption:* A study done by the INFORM (Information for Motorists) system of Long Island indicated that ramp signaling reduced fuel consumption by 6.7% (Jacobson et al., 2006).

- *Reduction in Vehicle Emissions:* As mentioned above, the same study from Long Island suggested that, after ramp signaling, there was a 17.4% reduction in carbon monoxide emissions, a 13.1% reduction in hydrocarbons, and a 2.4% decrease in nitrous oxide emissions (Jacobson et al., 2006). A study conducted by Cambridge Systematics (2002) indicated that ramp metering resulted in annual savings of 1,160 tons of emissions in Minnesota.

2.3. Warrants in the U. S.

2.3.1. MUTCD

In Chapter 4H, the 2003 Manual on Uniform Traffic Control Devices (MUTCD, 2003) states that implementation of ramp control signal is feasible only if at least one of the following occur:

1. Congestion recurs on the freeway because traffic demand is in excess of the capacity, or a high frequency of crashes exists at the freeway entrance because of an inadequate ramp merging area. A good indicator of recurring freeway congestion is freeway operating speeds less than 80 km/h (50 mph) occurring regularly for at least a half-hour period. Freeway operating speeds less than 50 km/h (30 mph) for a half-hour period or more would indicate severe congestion.

2. Controlling traffic entering a freeway assists in meeting local transportation system management objectives identified for freeway traffic flow, such as the following:

   - Maintenance of a specific freeway level of service.
   - Priority treatments with higher levels of service for mass transit and carpools.
   - Redistribution of freeway access demand to other on-ramps.

3. Predictable, sporadic congestion occurs on isolated sections of freeway because of short-period peak traffic loads from special events or from severe peak loads of recreational traffic.

However, it is also recommended that an engineering study be performed before any ramp signaling implementation takes place, in order to evaluate the physical and traffic conditions of the highway facilities, ramps and ramp connections, and surface streets that would be affected. To this end, "Capacities and demand/capacity relationships should be determined for each freeway section" (MUTCD, 2003).

The 2009 MUTCD (MUTCD, 2009) eliminates the guidelines stated in the 2003 version and references the Federal Highway Administration's (FHWA) Ramp Management and Control Handbook (Jacobson et al., 2006) as a tool to determine the need to implement freeway entrance ramp control signals. The handbook considers safety, congestion, convenience, access, ramp capacity and queues, and adjacent facility operations indicators to warrant ramp management, yet no specific criteria are suggested when evaluating such indicators.

2.3.2. Arizona

The Arizona Department of Transportation (ADOT) established different guidelines to implement ramp metering. These guidelines were originally developed by ITS Engineers and Constructors, Inc. and are listed in the Ramp Meter Design, Operations, and Maintenance Guidelines Manual from ADOT (2003). The course of action is based on nine warrants that determine whether ramp metering deployment is appropriate. Table 2-2 and Figure 2-1 describe each warrant and the analysis procedure that must be followed in order to determine whether to install a ramp meter.

2.3.3. California

Many cities in California have implemented ramp metering in an attempt to improve traffic conditions. However, no generalized criteria or standards have been made available to these cities since each district is responsible for their own ramp signaling development plan. The California Ramp Meter Design Manual states that "it is the District's responsibility to maintain an acceptable level of service on the freeway system, to make the most effective use of each transportation corridor, and to protect the public's investment in the system" (Caltrans, 2000). Nonetheless, some of the geometric design guidelines offered in the manual could influence the decision of ramp meter implementation, such as the following:

- Geometrics for single-lane ramp meter should be provided for volumes up to 900 vph. Where truck volumes (three axles or more) are 5% or greater on ascending entrance ramps to freeways with sustained upgrades exceeding 3% (i.e., at least throughout the merge area), a minimum 150 m length of auxiliary lane should be provided beyond the ramp convergence area.

- For multi-lane entrance ramps, if volumes exceed 900 vph and/or when a High Occupancy Vehicle (HOV) lane is determined to be necessary, a two- or three-lane ramp segment should be provided. On two-lane loop ramps, normally only the right lane needs to be widened to accommodate design vehicle off-tracking. Three-lane metered ramps are typically needed to serve peak-hour (i.e., commuting) traffic along urban and suburban freeway corridors.

- Freeway-to-freeway connectors may also be metered when warranted. The need to meter a freeway-to-freeway connector should be determined on an individual basis.

- Storage length for ramp meters have practical lower and upper output limits of 240 and 900 vph per lane, respectively. Ramp meter signals set for flow rates outside this range tend to have high violation rates and cannot effectively control traffic. Therefore, on a ramp with peak-hour volume between 500 and 900 vph per lane, a two-lane ramp meter may be provided to double the vehicle capacity stored in the available storage area. A single-lane ramp meter should be used when rates are below 500 vph and no HOV preferential lane is provided.

Table 2-2 Warrants for Installing Individual Ramp Meters

Warrant Name	Query		Yes	No
1. Recurring Congestion Warrant	Does the freeway operate at speeds less than 50 mph for a duration of at least 30 minutes for 200 or more calendar days per year?			
2. Collision History Pattern	Is there a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of inadequate merge area and congestion?			
3. Freeway Level of Service	Will the ramp meter or system of ramp meters contribute to maintaining a specific level of service (LOS) identified in the region's transportation system management (TSM) plan?			
4. Modal Shift	Will the ramp meter or system of ramp meters contribute to maintaining a higher level of vehicle occupancy through the use of HOV preferential treatments as identified in the region's transportation system management (TSM) plan?			
5. Redistribution of Access	Will the ramp meter or system of ramp meters contribute to balancing demand and capacity at a system of adjacent ramps entering the same facility?			
6. Sporadic Congestion Warrant	Does the ramp meter or system of ramp meters mitigate predictable sporadic congestion on isolated sections of freeway because of short peak-period loads from special events or from severe peak loads of recreational traffic?			
7. Total Volume Warrant	Is the ramp plus mainline volume greater than the tabulated criteria for the design hour?			
	Number of Mainline Lanes in One Direction including Auxiliary Lanes that Continue at least 1/3 Mile downstream from Ramp Gore	Criteria Volume Ramp Plus Mainline Volume Downstream of Gore (total vph)		
	2	2,650		
	3	4,250		
	4	5,850		
	5	7,450		
	6	9,050		
8. Right Lane plus Ramp Volume Warrant	Ramp signaling is warranted when the volume of the ramp plus the mainline right lane exceeds 2,100 vph. Is the criteria defined above met, during the design hour?			
9. Geometric Warrant	Does the existing or proposed ramp geometry permit safe and effective ramp signaling?			

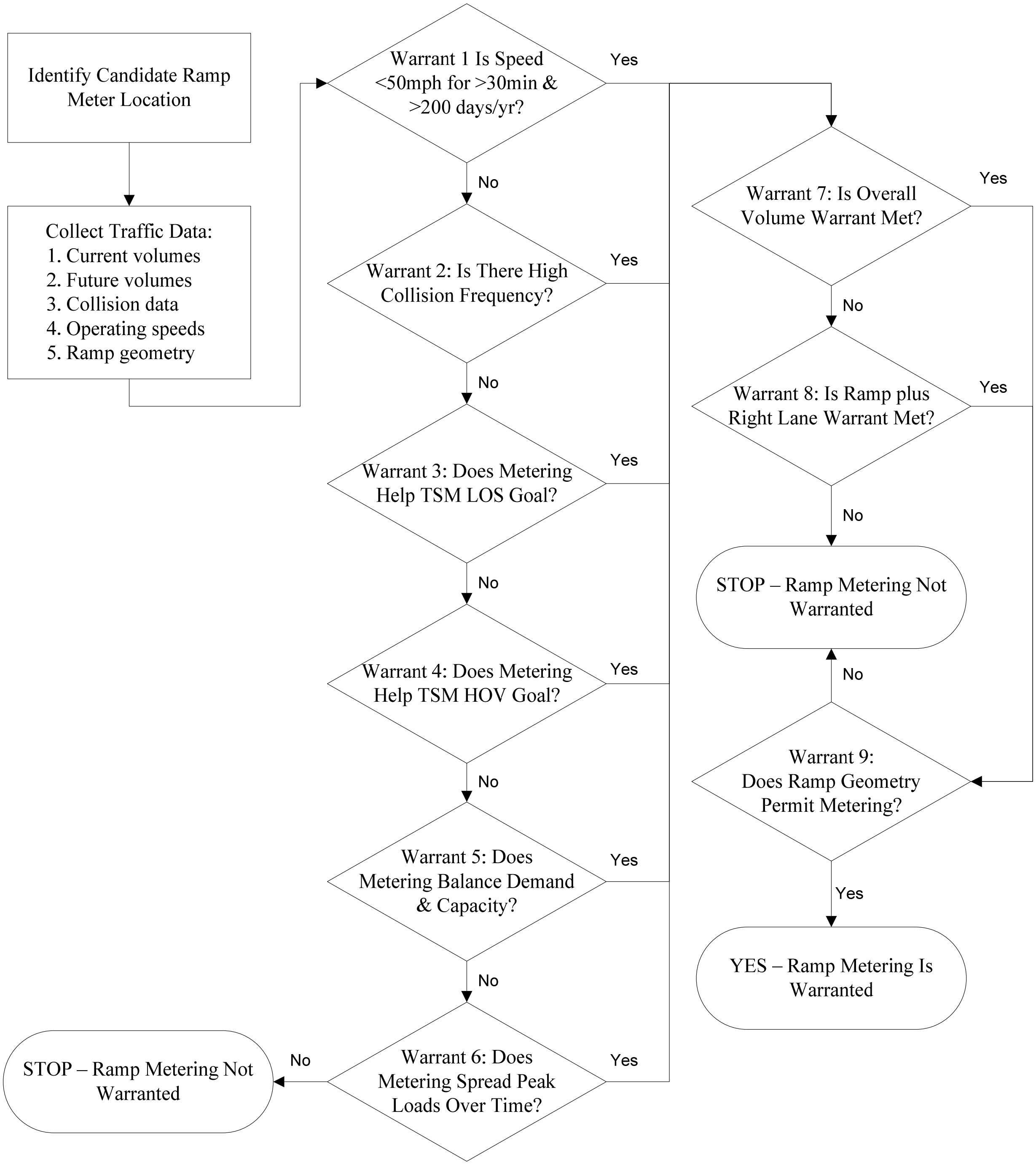


Figure 2-1 ADOT Ramp Signaling Warrant Flowcharts (ADOT, 2003)

- Ramp meter installations should operate in conjunction with, and complement, other transportation management system elements and transportation modes. As such, ramp meter installations should include preferential treatment of carpools and transit riders. Specific treatment(s) must be tailored to the unique conditions at each ramp location; however the standard or base treatment upon which other strategies are designed is the HOV preferential lane. An HOV preferential lane shall be provided at all ramp meter locations.

DKS Associates developed a report (DKS, 2008) for Caltrans and the San Joaquin Council of Governments for Northern San Joaquin Valley. The report suggested the following criteria for selecting "sketch-level ramp metering networks":

- *Congestion – Is the segment subject to recurring congestion? Is the segment immediately upstream or downstream of a bottleneck?* These areas are the primary candidates for ramp signaling.

- *Mainline Traffic Volumes – Does the current peak-hour volume-to-capacity (V/C) ratio exceed 0.6 (assuming a capacity of 2,000 vehicles per hour per lane) (vphpl)?* This is an indicator that a segment might be experiencing periodic congestion.

- *Number and Density of On-Ramps – Is there a high number and density of on-ramps?* This suggests potentially significant impacts due to merging and weaving, but also the potential to distribute control over multiple ramps.

- In subsequent steps, the ramp signaling network will be refined based on several factors, including:

  - *Mainline Congestion* – Does the average mainline speed fall below 30 mph?
  - *Mainline Volumes* – Does the forecasted V/C ratio exceed 0.8?
  - *Merge Volumes* – At an on-ramp merge point, does the sum of the on-ramp volume and the volume in the right-hand lane of the mainline approach or exceed 1,800 vph?
  - *Ramp Volumes* – Do ramp volumes fall within the practical limits of metering (i.e., between 240 and 900 vph for a single-lane on-ramp)?
  - *Ramp Design* – Is there sufficient storage and acceleration distance?
  - *Crash Rates* – Does the merge area experience crash rates significantly higher than average, and is the platooning of on-ramp traffic a possible contributing factor?
  - *Network Configuration* – Is there an alternative route that may be used for local trips? Is there a nearby on-ramp that is unmetered?

2.3.4. Colorado

The Colorado Department of Transportation (CDOT) uses a three-tiered approach to justify the installation of ramp signals in the Denver area (Torres, 2004). Two of the three tiers were derived from warrants established by ADOT and Caltrans. These two tiers provide threshold values in terms of traffic data in determining ramp signal installation. The third tier is more descriptive. It states that ramp signaling requires field observations and experiences with the current ramp meter system. The Tier 1 and Tier 2 criteria adopted by CDOT indicate that ramp signaling may be warranted under either of the following conditions:

- The mainline volume upstream of the gore plus the ramp volume overall exceeds the following thresholds (i.e., the same as ADOT):

  - Two mainline lanes have a volume up to 2,650 vph
  - Three mainline lanes have a volume up to 4,250 vph

- Four mainline lanes have a volume up to 5,850 vph

- The ramp volume exceeds the following thresholds (based on the Caltrans criteria):

    - A single-lane ramp has a volume up to 900 vph
    - Two-lane ramps have a volume above 900 vph

2.3.5. Minnesota

Cambridge Systematics, Inc. performed a ramp metering evaluation on behalf of the Minnesota Department of Transportation (MDOT) for the Twin Cities (Cambridge Systematics, 2001) According to their studies, the characteristics of freeway sections that are used to warrant ramp meter are as follows:

- peak-period speeds less than 48 kph (or less than 30 mph),
- vehicle flows between 1,200 to 1,500 vphpl,
- high crash rates, and
- significant merging problems.

2.3.6. Nevada

The Nevada Department of Transportation (NDOT) outlines the policy to warrant ramp metering in the HOV/Managed Lanes in the Ramp Metering Policy Manual (NDOT, 2006). This policy is intended to provide a basic framework to ensure statewide consistency for ramp metering implementation in Nevada. Hence, it is deliberately general and descriptive rather than quantitative. In this document, the following policies were provided as a starting point, or as a minimum set of recommended actions, to justify ramp metering:

- Justification for ramp metering deployment:
    - A system level assessment shall be conducted for any area considering ramp metering that will determine the need for, and impacts of, ramp meters. The initial region for this assessment is the Las Vegas area.
    - Corridors with routine congestion shall be considered for ramp metering.
    - Ramp meters shall be considered for deployment on ramps where a safety problem exists either on the ramp or at a location on the freeway facility at, or near, the ramp/freeway merge point.

- Justification of geographic extent:
    - Ramp meters shall be considered for deployment on a corridor-by-corridor basis, if ramp related problems are observed at multiple locations on a specific corridor, and if no such problems are observed on any other corridor.
    - Ramp meters shall be considered for deployment at an isolated location (i.e., without considering metering other nearby ramps) if a ramp related problem is observed at that location and similar problems are not observed at ramps immediately upstream or downstream of the ramp in question.

- Demand thresholds:

- Pre-metering demand on the ramp shall be used to determine the appropriate ramp metering flow control.

- Adjacent facility operations:
  - Ramp meters will be considered for deployment only if there is sufficient storage room on the ramp to hold vehicles that wait at the ramp meter. If existing storage room is deemed inadequate for times of day when the ramp meter is operational, ramp signal implementation may be allowable if sufficient, additional storage can be created by widening the ramp, or by other means (e.g., restriping lanes).

Although not directly stated as "ramp metering warrants," a number of issues were documented in NDOT HOV/Managed Lanes and Ramp Metering Implementation Plan as factors needing to be addressed when determining whether a ramp meter should be implemented. Some of these factors are subjective while others are more specific and include recommended threshold values. These factors/issues include (Chang et al., 2000):

- Safety:
  - High collision rates may indicate the need of ramp metering (no threshold is set).

- Congestion:
  - *Level of Service* – Freeway conditions approaching LOS D or worse may be candidates for ramp metering.
  - *Mainline Speeds* – Freeways with speeds consistently under 50 mph or peak-period average speeds under 40 mph may be candidates for ramp metering.
  - *Travel Time and Travel Time Reliability*– Described wherein no firm threshold value is indicated.

- Location analysis:
  - Extension of issues such as congestion or safety
  - *Ramp Demand* – Ramp metering may be appropriate when ramp demand ranges from 900 vph to 1,800 vph depending on flow control scheme (e.g., Single Lane and One car per Green, Single Lane and Two cars per Green, etc.).
  - *Ramp Storage Capacity and Queues* – Ramp metering may be appropriate when the ramp is capable of storing 10% of the pre-metered peak-hour volume.
  - *Merge Length* – Ramp metering may be appropriate when the minimum acceleration distance satisfies the requirements of the minimum merging distance provided by the American Association of State Highway and Transportation Officials (AASHTO) Green Book.

- Impact analysis:
  - *Diversion* – The level of diversion and its impact on nearby arterials should be studied before considering ramp metering implementation.
  - *Equity* – When analyzing the appropriateness of ramp meters for specific ramps, the distribution of benefits and drawbacks of ramp metering should be considered.
  - *Public Perception* – Public opposition to ramp meters and strategies devised for improving this outlook should also be taken into account before ramp metering implementation.

2.3.7. New York

The New York State Department of Transportation's (NYSDOT) Region 10 implemented ramp meters along the Long Island Expressway as part of their Long Island Intelligent Transportation System (LI ITS). NYSDOT's goal in operating ramp meters is to reduce congestion occurring on the freeway by staggering (metering) the volumes of traffic that can enter the highway mainline from on-ramps when the mainline is heavily congested (NYSDOT, 2010). NYSDOT provided peak-period ramp volumes as criteria to determine if a ramp is eligible for metering, as shown in Table 2-3.

Table 2-3 NYSDOT Region 10 Ramp Volume Criteria for Ramp Metering

Ramp Configuration	Ramp Volume Criteria (vph)	
	Minimum	Maximum
One Lane	240	900
Two Lanes	400	1,500-1,800

In addition to the above criteria, the New York State Highway Design Manual also recommended several guidelines adapted from the National Cooperative Highway Research Program (NCHRP) Report 155, Bus Use of Highways: Planning and Design Guidelines, as follows:

- Ramp metering should be considered wherever urban freeways operate below levels of service "D". Freeway lane density generally should exceed 25 to 30 vehicles per kilometer.
- Adequate parallel surface routes must be available for the traffic diverted from the ramps to improve overall network performance.
- Adequate ramp storage capacity must be available to prevent queues of vehicles waiting to enter the freeway from blocking local street circulation.
- Ramp metering should not be applied where queues exist, e.g., at freeway lane-drops or convergence points, or at freeway-to-freeway connectors.

The New York manual also referenced a report from the Connecticut Freeway Transportation System, providing the following ramp metering warrants regarding the available ramp storage:

- Ramp metering is considered feasible if the available ramp storage exceeds 10% of the pre-metered peak-hour volume.
- If there is storage for 5% to 10% of the peak-volume, metering may still be feasible; however, additional analysis is required and possible mitigating measures (e.g., additional ramp lane, queue detection, etc.) should be reviewed.
- Ramp metering is not considered feasible if the storage is less than 5% of the pre-metered peak-hour volume.

2.3.8. Oregon

The Oregon Department of Transportation (ODOT) included some basic criteria for the implementation of ramp signals in the ODOT Traffic Signal Policy Guidelines (ODOT, 2006). This document states that the reasons for the installation of ramp meters may include:

- to limit or regulate entering vehicle volume at a merge point,
- to limit or regulate traffic flow through a downstream bottleneck, and
- to limit volume diverted to a specific entrance ramp.

Although this document states that ramp meters may be provided at any freeway entrance ramp regardless of traffic volumes, and that ramp meters are not intended to divert long-distance trips onto the local road system, it is also mentioned that the practical limits of metered volumes are 240 to 900 vph for a one-lane ramp and 1,650 vph for a two-lane ramp.

2.3.9. Texas

The Texas Manual on Uniform Traffic Control Devices (TMUTCD) provides some descriptive guidelines for when a ramp signal may be justifiably installed. These guidelines are the same as the guidelines presented in the 2003 version of MUTCD.

In 2009, the Texas Department of Transportation (TxDOT) conducted an in-depth study and developed three sets of criteria for justifying the installation of ramp signals. The development effort was based on the literature review of the then current ramp metering operation practices in Texas, as well as in other states, and a simulation study conducted by the Texas Transportation Institute (TTI). These criteria include traffic flow and safety considerations among other considerations (Balke et al., 2009). TxDOT recommended that installation of ramp control signals should be considered if the following traffic flow conditions are met:

1. The freeway regularly operates at speeds of less than 50 mph for at least a half-hour period during the day (presumably during the peak-period).

2. The ramp sustains a minimum flow rate of at least 300 vph during the peak-periods.

3. The average traffic flow rate of the two right-most lanes during peak-periods exceeds 1,600 vehicles per hour per lane (vphpl) for entrance ramps with acceleration lanes of 500 feet or less, and this threshold level increases as the length of the acceleration lane on the ramp increases (see Figure 2-2).

4. The combined traffic flow rate in the rightmost freeway lane plus the flow rate on the entrance ramp during peak-periods exceeds a minimum of 2,300 vphpl for entrance ramps with acceleration lanes of 500 feet or less. This threshold level increases as the length of the acceleration lane on the ramp increases (see Figure 2-3).

Criterion 1 is included because they are explicitly presented in the TMUTCD. It also states that "ramp control signals should be installed where flow entering the freeway routinely causes congestion to form on the freeway, and where operations of the freeway would be improved as a result of installing the control signal."

Criteria 2, 3, and 4 were established via a simulation study done by TTI. Criterion 2 is the minimum ramp volume that should be observed before a ramp signal can be warranted. Criterion 3 is intended to ensure that there must be a minimum amount of traffic existing on the mainline freeway. The two rightmost lanes were chosen because they are most likely to be affected by the traffic merging from the ramp. The study found that the average threshold level of traffic in the two rightmost lanes increases as the length of the acceleration lane increases. Thus a graph was plotted, as illustrated in Figure 2-2, to show the minimum two rightmost lanes' (defined as "main lane" in the graph) volume thresholds for different lengths of the ramp acceleration lane. When applying this criterion, the "main lane" volume is plotted over the corresponding acceleration lane length to determine if the threshold value is exceeded. Criterion 4 was established because the TTI study found that "there was a threshold of entering ramp traffic and traffic in the rightmost lane of the freeway where installing a ramp control signal can result in improved performance of the freeway". Similar to Criterion 3, this warrant is plotted (see Figure 2-3) for better clarity.

From a safety perspective, TxDOT recommends that the installation of ramp control signals may be justified based on the following three criteria:

1. The rate of crashes in the immediate vicinity of the ramp exceeds the mean crash rate for comparable sections of freeway in a metropolitan area;

2. The ramp length (acceleration distance) permits a vehicle starting from a stop at the signal to reach the prevailing speed of the freeway traffic in the merge area so as to prevent an unacceptable speed differential in the merge area; and/or

3. Sufficient storage length exists upstream of the ramp control signal to prevent queues from impeding operations on the frontage road or surface street intersection.

The second safety-oriented criterion was developed based on vehicle kinematics properties. It is assumed that the interacting ramp and freeway traffic vehicles must be able to maintain a desirable time to collision (TTC) after the merge; a TTC value lower than a specified threshold indicates an unsafe merge condition at the ramp meter. A lower TTC depends on the acceleration lane length on the ramp, the prevailing mainline traffic speed, and the minimum speed that a vehicle needs to attain after accelerating in the merging area.

The study established this criterion by analyzing the ramp speed requirements using a fixed ramp vehicle acceleration rate of 3.22 feet per second square (ft/s^2) and the TTCs of 1.5, 1.75, and 2.0 seconds. Free Flow Speeds (FFS) of 55 to 75 mph were used to measure the prevailing mainline traffic speed. Table 2-4 shows the minimum speed that a vehicle needs to attain after traveling on the acceleration lane for it to complete a safe merge, given different combinations of mainline FFS and critical TTCs.

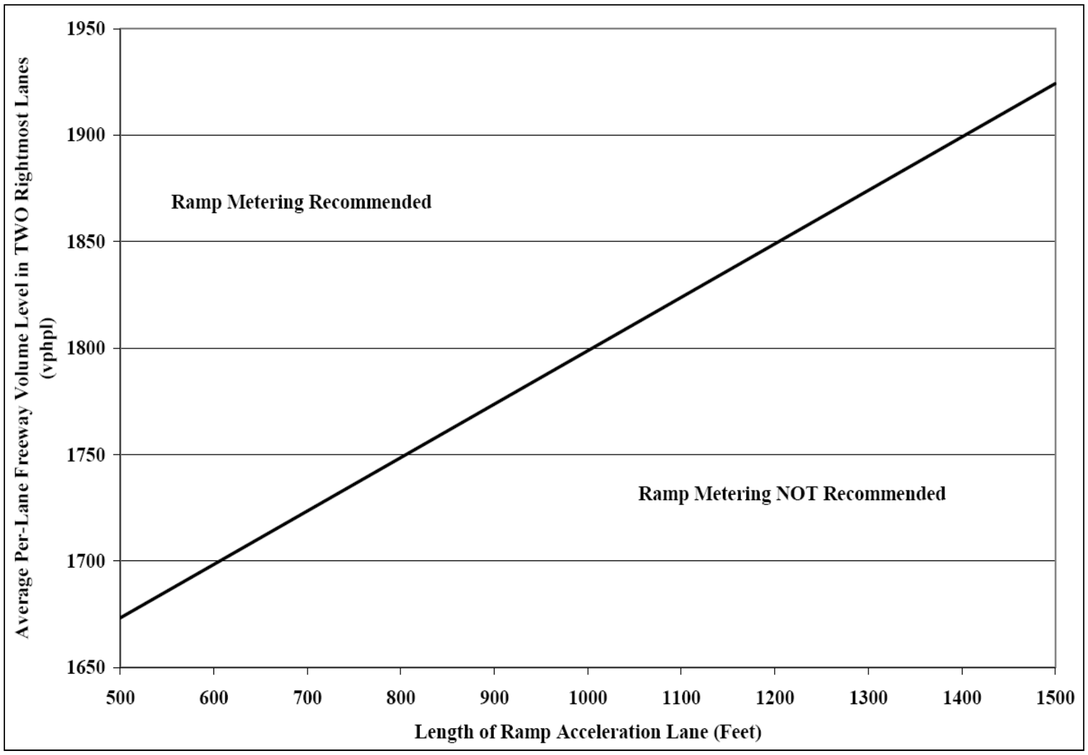


Figure 2-2 TxDOT Ramp Metering Warrant - Freeway Main Lane Volume Thresholds (Average of Two Rightmost Lanes)

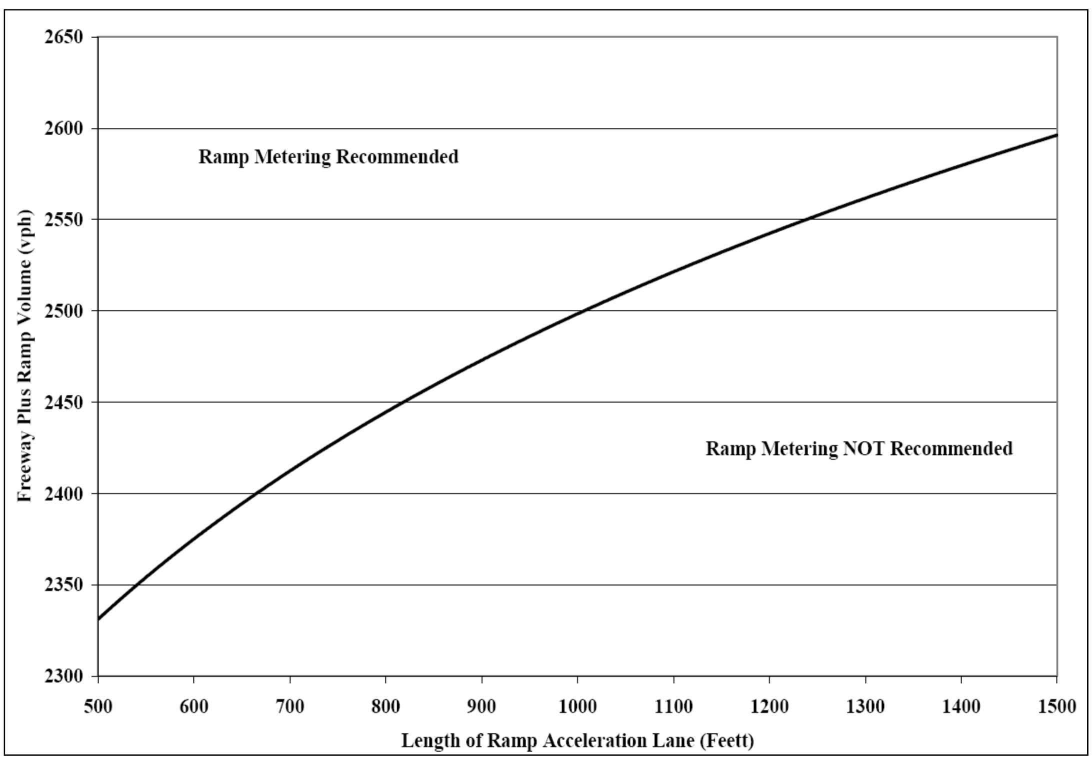


Figure 2-3 TxDOT Ramp Metering Warrant - Combination of Ramp plus Freeway (Outside Lane Only) Volume Thresholds

Table 2-4 Minimum Speed Requirements to Ensure Safe Merging

FFS (mph)	Minimum Required Ramp Vehicle Speed (mph)		
	Min TTC 2.0s	**Min TTC 1.75s**	**Min TTC 1.5s**
75	57.0	55.3	53.8
70	54.1	52.4	50.8
65	50.8	49.0	47.4
60	47.4	45.5	44.0
55	44.0	42.4	40.6

The final criterion is displayed graphically as shown in Figure 2-4. When applying this criterion, the minimum ramp vehicle speed requirement as given by the mainline FFS and the minimum TTC (headway) is identified, and a minimum sufficient acceleration distance for the ramp vehicle can then be calculated by assuming an acceleration rate of 3.22 ft/s^2.

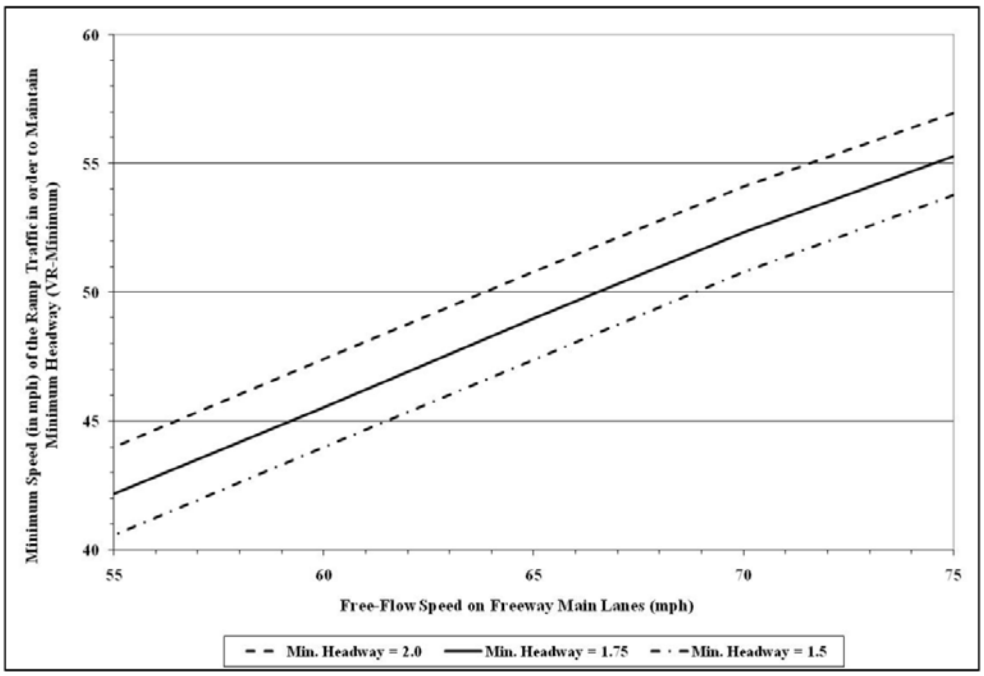


Figure 2-4 TxDOT Ramp Metering Warrant - Speed Requirement for Ramp Vehicles at the Merging Area

The fourth criterion addresses the concern of adequate storage space between the ramp signal and adjacent intersection. The purpose of a ramp control signal is to disperse platoons of traffic released from upstream signalized intersections. There is a potential that the queuing traffic on the ramp might block the intersection if the arrival rate of traffic leaving these intersections is greater than the metering rate. Figure 2-5 graphs this criterion. Based on the traffic on a given ramp, a required storage length can be identified using the graph. If available storage space is greater than or equal to the required storage space, then sufficient space exists for installing the ramp meter. This criterion is believed to have been taken from a design criterion for ramp metering prepared for TxDOT (Chaudhary and Messer, 2000). However, the original literature describes it in only a cursory fashion, and it was not explained how this criterion was established.

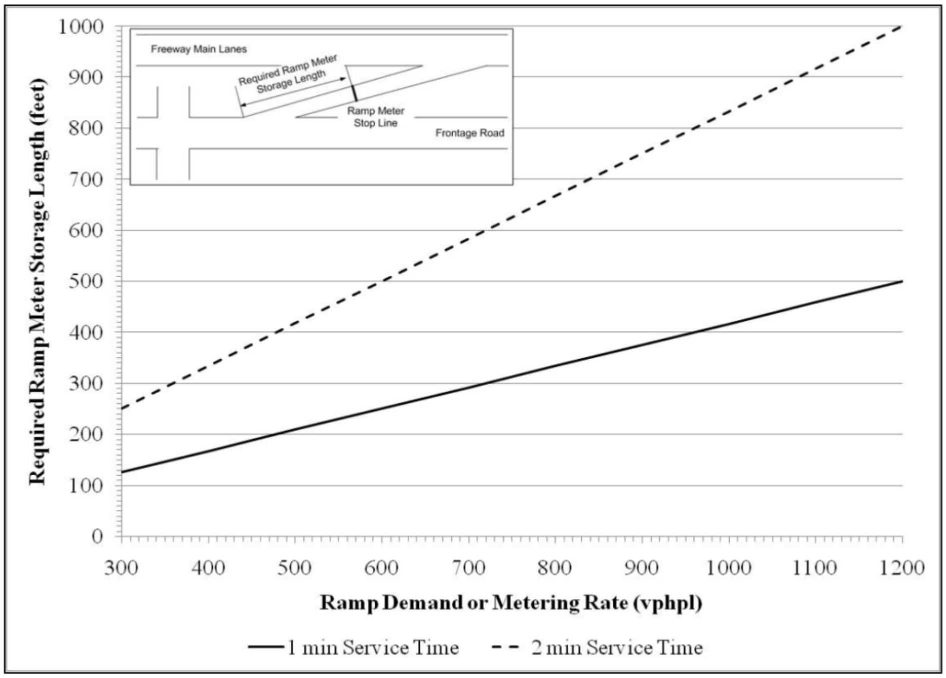


Figure 2-5 TxDOT Ramp Metering Warrant - Required Length to Store Waiting Vehicles

2.3.10. Utah

According to the Advanced Traffic Management System Design Manual (Transcore, 2001) of the Utah Department of Transportation (UDOT), the determination of whether ramp metering is warranted is ultimately dependent on engineering judgment, but should also be coordinated with the UDOT Traffic and Safety Division to determine the type of ramp metering to be employed at specific locations. Because the transportation engineering community has not established a universal standard for ramp metering warrants, the UDOT uses the MUTCD criteria.

The MUTCD (2003) does indicate that ramp metering may be justified when total expected delay to traffic in the freeway corridor, including freeway ramps and surface streets, is expected to be reduced with ramp metering, and when at least one of the three following conditions exists:

- Recurring congestion due to traffic demand in excess of capacity
- Traffic management objectives are met
- Periodic congestion due to special events or severe peak loads occurs

In addition, another qualitative warrant for ramp metering is consideration of system-wide metering operations. It is believed that ramp metering is most effective at improving vehicle flow along a corridor when it is deployed on all adjacent ramps. Within a network of freeways, ramp metering is capable of balancing flows and equalizing volumes. Implementation of ramp metering at all ramps along a corridor or network also provides a consistent environment for motorists. Therefore, even if the traffic conditions at a particular entrance do not warrant ramp metering, it may be beneficial to implement ramp metering at specific locations in order to achieve system-wide benefits.

The UDOT also uses two quantitative warrants for justifying ramp metering. These guidelines agree with numerical criteria that have been used by other states. The two warrants are as follows and illustrated in Tables 2-5 and 2-6 respectively:

- Total Mainline Volume and Ramp Volume (as shown in Table 2-5)
- Ramp Volume (as shown in Table 2-6)

Table 2-5 UDOT Ramp Metering Warrant – Total Mainline and Ramp Volume Threshold

Number of Lanes	Criteria Volume (vph)
2	2,650
3	4,250
4	5,850
5	7,450
6	9,050
7	10,650

Table 2-6 UDOT Ramp Metering Warrant –Ramp Volume Threshold

Ramp Volumes (vph)	HOV%	Recommended Lane Configuration
< 180	-	Signaling not recommended
180 ~ 600	-	One-lane metered ramp
600 ~ 900	< 10 %	One-lane metered ramp
600 ~ 900	> 10 %	One-lane metered ramp, or Two-lane ramp with one lane metered and one HOV lane
900 ~ 1,080	< 10%	Two-lane ramp with both lanes metered
900 ~ 1,080	> 10%	Two-lane ramp with both lanes metered, or Two-lane ramp with one lane metered and one HOV lane
1,080 ~ 1,350	< 10%	Two-lane ramp with both lanes metered
1,080 ~ 1,350	> 10%	Two-lane ramp with both lanes metered, or Three-lane ramp with two lanes metered and one HOV lane
1,350 ~ 1,720	< 10%	Three-lane ramp with all lanes metered
1,350 ~ 1,720	> 10%	Three-lane ramp with all lanes metered, or Three-lane ramp with two lanes metered and one HOV lane
> 1,720	-	Consider alternate metering strategies, or no metering

The first warrant identifies the volume at which a queue is expected to form on the mainline. If a queue develops on the mainline, it may be beneficial to deploy ramp metering to regulate the flow of additional ramp vehicles onto the mainline. Therefore, if the criteria volume for the number of lanes indicated in the table is exceeded, then ramp metering may be warranted to prevent mainline queuing.

In Table 2-5, number of lanes is the number of continuous mainline and ramp lanes present from the ramp gore point 500 meters downstream of the ramp gore. In other words, a ramp lane must

continue at least 500 meters past the ramp gore to be counted as a lane. The criteria volume referred in the same table is the approximate total volume of both the mainline and ramps at which a queue is expected to form on the mainline if ramp metering is not deployed.
UDOT also utilizes ramp volume to justify ramp metering and recommend lane configuration. The threshold values and the corresponding recommended configuration is show in Table 2-6. The configuration also considers the deployment of High Occupancy Vehicle (HOV) lanes combined with ramp metering. The recommendation is based on the ramp volume and the percentage of HOV on the ramp. From Table 2-6, a ramp vehicular volume of 180 vph is considered as a threshold value to warrant ramp metering. This is a relatively lower threshold compared to similar warrants from other states.

2.3.11. Virginia

A literature review done by the Virginia Transportation Research Council states that there have been a number of attempts to develop "warrants" for ramp metering; however, this has proven difficult because of many factors involved (Arnold Jr., 1998). The Virginia Transportation Research Council therefore cited the 1998 version of the MUTCD to identify general guidelines for the successful implementation of ramp meters, as follows:

- The installation of ramp meters should be preceded by an engineering analysis of the physical and traffic conditions on the highway facilities likely to be affected. This should include the determination of capacities and demand/capacity relationships for each freeway section, thus enabling the identification of potential problems and mitigating strategies.

- Consideration should be given to public acceptance potential and enforcement requirements, as well as alternate means of increasing capacity, reducing demand, or improving characteristics of the freeway.

- Generally, the installation of ramp meters may be justified when the total expected delay to traffic in the freeway corridor, including freeway ramps and local streets, is expected to be reduced with ramp control signals and when at least one of the following instances occur:

    - There is recurring congestion on the freeway due to traffic demand exceeding capacity or there is recurring congestion or a severe crash hazard at the freeway entrance because of an inadequate merging area. It is suggested that operating speeds of less than 50 mph that occur for a period of half an hour are an indication of developing congestion problems. Speeds of less than 30 mph for a half-hour period are an indication of severe congestion.

    - Signals are needed to accomplish transportation system management objectives identified locally for freeway traffic flow. Examples would include maintenance of a specified level of service or the provision of higher levels of service for transit and HOVs.

- Signals are needed to reduce sporadic congestion on isolated sections of freeway caused by short-period peak traffic loads from special events or from severe peak loads of recreational traffic.

After reviewing the positive and negative impacts of ramp meters, the Transportation Research Council then identified the following guidelines for determining candidate locations for new ramp metering implementation (Arnold, 1998):

- The freeway is usually plagued with poor traffic flow conditions in the peak-periods, such as speeds of less than 30 mph, low volumes per lane, levels of service of E or F, and stop-and-go traffic.
- There are numerous crashes on the freeway, especially in on-ramp weaving areas.
- There are obvious merging problems occurring at freeway on-ramps.
- Heavy traffic volumes occur at closely spaced on-ramps.
- Metering will accommodate the ramp demand volumes from both a maximum and minimum standpoint.
- There is adequate vehicle storage on the ramp.
- A freeway management system is being planned.

2.3.12. Washington

A study done by Wilbur Smith Associates (2006) indicates that the Washington State Department of Transportation (WSDOT) uses the following four characteristics as part of their criteria to determine if ramp metering should be deployed:

- Number of crashes (no threshold number set)
- Evaluation of local condition (qualitative, not quantitative)
- Lane capacity (1,500 vphpl)
- Occupancy (20%)

The study also mentions that WSDOT prefers to apply ramp metering corridor-wide as opposed to site-specific installations. In doing so, the likelihood of motorists using the adjacent ramps as bypass for the metered ramp can be reduced and the ramp metering effect of smoothening traffic will be more effective. WSDOT relies on occupancy data collected from their detectors to justify if ramp metering will be beneficial. However, these warrants are mostly qualitative.

2.3.13. Wisconsin

The Wisconsin Department of Transportation (WisDOT) ramp metering warrants are documented in a March 2006 report conducted by Wilbur Smith Associates (2006). These warrants include:

- *Mainline Volume Criteria* - Vehicle flow rates of at least 1,200 vphpl (approximately 20% to 30% occupancy).
- *Ramp Volume Criteria* - Ramp volumes of at least 240 vph (or 400 vph for two lanes).
- *Speed Criteria* - A mainline speed of 30 mph or less at peak times.
- *Safety Criteria* - Significant merge related crashes (80 crashes per 100 million vehicle

miles).

- *Alternate Route Criteria* - The presence of an alternative route for motorists on the arterial network to avoid the delays on entrance ramps created by a ramp meter (yes or no based on engineering judgment).
- *Corridor Criteria* - In most deployments, ramp metering is addressed at a corridor level; thus, a single isolated ramp meter is rare, and a series of ramp meters with a non-metered ramp in between is very infrequent.
- *Ramp Geometric Criteria* - Three primary criteria include storage space, adequate acceleration distance and merge area beyond the meter, and sight distance.
- *Funding Criteria* - An evaluation of potential funding sources should be completed to determine if there is sufficient support for the project.

2.4. Warrants Outside the U.S.

2.4.1. Australia

Australia's ramp metering guidelines are documented in their Freeway Ramp Signals Handbook (Burley and Gaffney, 2010). This handbook was developed by VicRoads, a state government agency that assists the government in achieving its integrated transport policy objectives. The Australian ramp signaling guidelines are highly dependent on the identification of congestion and bottlenecks through the analysis of freeway flow data. The handbook states that the analysis generally involves an assessment of flow, speed, and occupancy information along the freeway. This assessment identifies bottlenecks at merge and other locations, and also considers the frequency and duration of flow breakdown from day-to-day traffic (or the potential for flow breakdown). Their guidelines are stratified by two different ramp signaling strategies as described below.

- An isolated ramp signal may be provided when the breakdown of the mainline freeway flow is localized and is clearly associated with platoons of traffic entering at a particular ramp.

- A route-based treatment (corridor-wide ramp signaling deployment) is required where,

    - the congestion and flow breakdown occurs at a number of bottlenecks over a freeway section;
    - the flow breakdown occurring at a particular location cannot be addressed by an isolated ramp signal (i.e., the freeway flow causing the flow breakdown results from a combination of a number of upstream entry ramps); or
    - the peak-period traffic volume for the freeway mainline between interchanges is 1,700 vphpl or more, without flow breakdown.

The above guidelines provide justification for ramp signaling implementation on existing freeways, and also propose guidelines for the installation of ramp signals under new contracts. Based on the above discussed guidelines, the only quantifiable criterion used is the mainline volume of 1,700 vphpl.

2.4.2. New Zealand

In New Zealand, the New Zealand Transport Agency (NZTA) is responsible for nationwide transportation management, which includes ramp signaling operation. The agency installed over 30 ramp signals along its major freeways; however, there were no formalized ramp signaling warrants proposed by NZTA. Nevertheless, in 2004, a ramp signaling trial was successfully launched in New Zealand. The following information is included in the document for the trial project, which may serve as guidelines for future ramp signaling implementation (Brown et al., 2010):

- enough distance to merge from two lanes to one lane on the ramp is provided,
- enough distance for sufficient acceleration to merge onto the freeway is provided, and
- there is enough space for ramp storage

It is also mentioned that the ramp under examination should provide enough ramp space to allow drivers to accelerate to approximately 80 kph before merging onto the freeway; thus, approximately 120 meters of storage in each lane on the on-ramp is needed (Brown et al., 2010).

2.4.3. U. K.

The U. K. Highways (2005) Agency proposed ramp metering criteria for assessing the suitability of a site for ramp metering based on both traffic and physical characteristics of the ramp. These criteria were derived from experience gained with existing ramp metering practices in the U. K. Table 2-7 lists the threshold values for the established measurements. Furthermore, Figure 2-6 shows a flow chart that illustrates the procedures for evaluating the criteria at the individual ramp site.

Table 2-7 U. K. Ramp Metering Criteria

Parameter	Minimum Value	Maximum Value
Congestion (hours below 50 kph per year)	250	No maximum value
Upstream mainline flows (vph across 3 lanes)	4,000	5,000
Slip road flows (vph per lane)	400	900
Slip road flow as percentage of upstream flow (%)	5	30
Average mainline speeds in congestion (kph)	No minimum value	70
Slip road length (local road to start of merge in meters)	300	No minimum value
Merge length (meters)	205	No minimum value

2.4.4. Netherlands

Ramp signaling was first implemented in the Netherlands in 1989 to relieve motorway congestion, improve merging behavior, and discourage drivers (known locally as "rat runners") from exiting the facility at a short distance to further avoid congestion on the motorway (Kenis and Tegenbos, 2011). Since the 1990s, the Netherlands has been using dynamic traffic management as a tool to alleviate the negative impacts of increased traffic demand. The following two conditions allow for the implementation of ramp signaling as a means to improve traffic flow (Taale and Middelham, 2000):

Figure 2-6 U.K. Highways Agency Flow Chart to Warrant Ramp Metering (Highways Agency, 2005)

- On-ramps are located close to a bottleneck.
- On-ramps cause disruptions in the traffic stream on the motorway due to the merging process caused, for example, by platoons of vehicles coming from a signalized intersection.

2.4.5. EURAMP

The European Ramp Metering Project (EURAMP) is founded by the European Union (EU). The main objective of this project is to advance, promote, and harmonize ramp metering control measures in Europe, with the aim of improving safety and efficiency of traffic flow. EURAMP developed a Handbook of Ramp Metering (Papageorgiou and Papamichail, 2007) which reflects the major conclusions and achievements of EURAMP. This handbook aims to provide a best-practice guide to help road authorities and consultants in properly designing, installing, and operating ramp metering systems. Although there are no streamlined or quantified warrants for ramp metering implementations, the manual proposes a “suitability/feasibility study” to determine if ramp metering will be beneficial. The following steps are included in the study:

- Observation of the daily pattern of traffic conditions (without crash), e.g., based on available traffic measurements, and analysis of the traffic situation: Where do congestions first appear? For what reason? What is their extent in space and time? What are the measured flows during congestions?

- Preliminary assessment of the potential ramp signaling impact: Is it possible to increase the traffic flow efficiency via ramp signaling actions, e.g., avoid or retard recurrent congestion so as to increase motorway throughput? Is there sufficient ramp storage space for reasonable ramp signaling operations?

- How does ramp signaling fit within a more general traffic management scheme that may already include other control measures (e.g., driver information or route guidance, variable speed limits, lane controls, etc.)?

In addition to the suitability study, EURAMP also recommends using traffic simulators (microscopic or macroscopic) to more thoroughly investigate issues such as potential control strategies, impact on adjacent road network, etc., before a decision regarding ramp metering is made.

2.4.6. EASYWAY

EASYWAY (2007 to 2013) is a European-wide program for Intelligent Transportation Systems (ITS) deployment on the Trans-European Road Network (Laoide-Kemp et al., 2009). Its affiliates include road authorities and transportation engineering practitioners from throughout Europe. A majority of European countries that have implemented ramp signaling are partners of EASYWAY. These countries include, but are not limited to, Belgium, England, France, Germany, and Netherlands. EASYWAY contains clear objectives for traffic safety, network performance, and environmental impacts on both a regional and European scale by considerably strengthening the European cooperation and harmonization of its ITS practices.

In their latest version of “Guideline for the Deployment of Ramp Metering” (Laoide-Kemp et al., 2009), the conditions for the deployment of ramp metering are provided based on the following attributes:

- Physical condition:
    - Sufficient storage space on the on-ramp is required (storage space is defined as beginning at the urban road to the start of the merge).
    - Adequate acceleration distance to the mainline merge point; if this is limited it may not allow all types of vehicles to reach the mainline speed and enter safely.
    - Limited sight distance caused by road curvature and vegetation may require additional advanced warning of ramp metering operation.

- Network:
    - Frequently occurring flow breakdown on the main carriageway, within the range of access points, attributed to the merging traffic.
    - Closely spaced ramps; i.e., less than 1 mile apart (may not allow enough merging distance for vehicles to enter and exit the motorway at the required speed).

- Traffic flow:
    - High on-ramp traffic flow with associated high mainline flow, to ensure it has an impact on the main carriageway; however, if demand is too high, ramp metering queue protection will be forced to set the signals to green to prevent tailbacks interfering with urban traffic.
    - Section related congestion and/or crash development on the upstream segment of the access point is considerably higher than comparable mean values.

- Weather:
    - Motorway capacity differences become more pronounced in adverse weather conditions such that traffic responsive control strategies will adapt better to changing conditions (such as weather related congestion) than fixed time strategies.

- Safety:
    - High frequency of crashes within the merging area of an access point.

- Environment:
    - Local environmental conditions should be considered; trade-off between possible increased queuing at on-ramps and increased free-flow.

- Freight:
    - If there is a high percentage of Heavy Goods Vehicles (HGVs) on the slip road, they may take longer to reach mainline speed, especially on steeper gradients; HGVs can be given priority using dedicated lanes, which can provide safety benefits and improve freight mobility.

2.4.7. ENTERPRISE

ENTERPRISE is a multi-national consortium devoted to the advancement of Intelligent Transportation Systems (ITS). The partners of this program include active ITS states from across the U.S., and agencies from Europe and Canada. Its main purpose is to develop and carry out a joint research program to evaluate and deploy ITS technologies.

One ENTERPRISE project is aiming to develop ITS warranted installation parameters, guiding the initial decisions of whether or not to deploy certain ITS solutions such as Closed Circuit Television (CCTV), Dynamic Message Sign (DMS), Ramp Metering, etc. Among these warrants, three different warrants were developed based on different scenarios in order to determine if ramp metering would be justified (Enterprise, 2010).

Warrant 1 "*Corridor-wide Ramp Meter Deployment*" deals with ramp meters along a 3 to 6 mile stretch of freeway. Ramp metering is warranted under the following conditions:

- During the AM or PM peak-period, the zone in consideration has at least 30 minutes per commute day (measured in five-minute increments) where the demand equals or exceeds 95% of the downstream capacity, according to the following equation:

$$MV + OR > (ER + MC) \times 0.95$$

  where,

  MV = upstream mainline volume (in veh/5 minutes),
  OR = the sum of on-ramp volumes of ramps within the zone (in veh/5 minutes),
  ER = the sum of off-ramp volumes within the zone (in veh/5 minutes), and
  MC = downstream mainline capacity (in veh/5 minutes).

- Platoons from signalized intersections are recognized to adversely impact all on-ramps feeding onto the freeway segment under consideration. For example, if hourly volume, based on maximum 30-second volume readings projected to hourly volumes, exceeds 1,100 vph (regardless of overall hourly volume).

- There is one or multiple area(s) within the zone where crashes are understood to exceed the typical crash rate (at the ramp gore point or within 500 feet in either direction of the gore point) for the metropolitan area.

- Volumes at ramps being considered for meters, within the zone, fall within the range of 240 to 900 vphpl during peak-periods.

Warrant 2 "*Isolated Ramp Meter Deployment*" approaches the possibility of having an isolated ramp meter within a corridor. Ramp metering is warranted when:

- The freeway operates at speeds of less than 50 mph for duration of at least 30 minutes for 200 or more calendar days per year.

- There is a high frequency of crashes (collision rate along the freeway exceeds mean collision rate in the subject metropolitan area) near the freeway entrances because of an inadequate merging area or due to congestion.
- The ramp meter will contribute to maintaining a specific level of service (LOS) identified in local transportation plans and policies.
- The ramp meter will contribute to maintaining a higher level of vehicle occupancy through the use of HOV preferential treatments as identified in the region's transportation system management (TSM) plan.
- The ramp meter will contribute to balancing demand and capacity at a system of adjacent ramps entering the same freeway facility.
- The ramp meter mitigates predictable sporadic congestion on isolated sections of freeway because of short peak-period loads from special events or from severe peak loads of recreational traffic.
- The total mainline-ramp design hour volume (mainline volume plus ramp volume) exceeds a predefined threshold value (see Table 2-8).
- The total volume of the sum of traffic in the rightmost lane and the ramp exceeds 2,100 vph during the design hour.
- Platoons from signalized intersections are recognized to adversely impact the ramp under consideration; this occurs if hourly volume, based on maximum 30-second volume readings projected to hourly values, exceeds 1,100 vph (regardless of overall hourly volume).
- Volumes at ramps being considered for meters, within the zone, fall within the range of 240 to 900 vphpl during peak-periods.

Table 2-8 ENTERPRISE Ramp Metering Warrant 2 – Volume Thresholds

Number of Mainlines per direction	Volume (vph)
2 lanes	2,650
3 lanes	4,250
4 lanes	5,850
5 lanes	7,450
6 lanes	9,050

Warrant 3 is "*Ramp Signaling during Work Zone Activity*," and deals with metering specific ramps to improve safety and traffic flow during construction. Conditions for this warrant are as follows:

- There is a temporary reduction in capacity of through-lanes due to either a reduction in the number of lanes, or a reduction in the width of lanes of traffic, causing a backup of traffic during peak-periods.
- There is a temporary change in the geometry or length of the acceleration lane that will potentially have a negative impact on ramp traffic merging with the mainline traffic.
- There is a desire to discourage the use of the ramp during road work.

2.5. Summary

This chapter identifies and reviews the existing guidelines/warrants used for justifying the implementation of ramp signaling (or metering) in the U.S. as well as other countries. The purpose of this review is to gain a sound understanding of the current status of warrant development for ramp signals, capture valuable insights of ramp signaling justification criteria, and obtain ideas/inspiration regarding how to develop future ramp signaling warrants.

Ramp signaling guidelines from 12 states in the U.S., four other countries, and three agencies were reviewed in this chapter, although there are more agencies/geographical locations which have also implemented ramp signaling. This is believed to be the most extensive literature review focusing on ramp signaling warrants since May 2009, when TTI completed their ramp signaling warrant study for TxDOT. The findings of the literature review effort are summarized below:

- Despite the increased popularity of ramp signaling, there are limited resources pertaining to the criteria/warrants needed to justify the installation of ramp signals. There are very few published or formalized warrants that could be employed by a transportation planner/engineer, or a policy maker when attempting to determine the need for the deployment of ramp signaling at a ramp location.

- Ramp signaling has been implemented the most in the U.S., hence the experience and information regarding ramp signals has been accumulated largely from the U.S. Ramp signaling has also been promoted in other countries such as Australia, New Zealand South Africa, and significantly in several European countries. Several projects/programs were set up in Europe to promote the application of ramp signaling, including EASYWAY and EURAMP. However, the majority of studies and research regarding ramp signaling warrants are still mostly based on the practices in the U.S.

- Development of a set of ramp signaling warrants has proven challenging because of various factors involved. Justification of ramp signaling is often site-specific making it difficult to identify transferable warrants. Thus, a number of agencies have identified their ramp signaling locations with pilot projects instead of applying a set of warrants. This obscures, but in no way diminishes the need of ramp signaling warrants.

- Among the few existing warrants, a number of individual warrants are quantitative and objective, while others are qualitative and subjective, such as those provided by MUTCD, Nevada, and New Zealand. These criteria are mostly descriptive and provide a wide variety of conditions that may justify ramp signaling; for instance, "there is adequate vehicle storage on the ramp" or "there are obvious merging problems occurring at freeway on-ramps." These warrants are not suitable for ramp signaling location selection during the preliminary phase of a ramp signaling project when quick decisions need to be made.

- In addition to establishing a set of individual warrants (subjective or objective), several agencies also developed a systematic methodology, typically formatted as a flow chart, to determine whether ramp signal installation is justified (e.g., ADOT and U.K. agencies).

This means a single, or several, criteria among the set may not warrant its implementation. Nonetheless, not all criteria within a set need to be met to warrant ramp signaling at a site. Some criteria may have higher priority than others in determining the justification (e.g., safety concerns) such that ramp signaling may be deemed to be necessary by satisfying that particular criterion.

- A majority of agencies suggest that the implementation of ramp signals should be preceded by an engineering study. Moreover, engineering judgment based on local conditions is required before a ramp signal is warranted.

- There are two major resources documenting ramp signaling guidelines if a formalized set of warrants is desired. They are documented in “Ramp Signaling Implementation Guidelines Manual” and “Ramp Signaling Design Manual”. However, there are no separate warrants developed for planning and implementation purposes.

- A majority of the existing ramp signaling warrants is based on implementation experiences, such as positive and negative impacts of ramp signaling; others, however, are based on pilot projects. Given this discrepancy, researchers have started to use more analytical procedures (e.g., micro simulation) in developing ramp signaling warrants.

- Based on the literature reviewed, some criteria used to warrant ramp signaling deployment are relatively easy to quantify. These criteria can be classified into the following categories:

    - Traffic criteria (e.g., mainline volume, ramp volume, and mainline speed, etc.)
    - Geometric criteria (e.g., ramp storage and length of acceleration lane)
    - Safety criteria (e.g., crash rate)

- There are some other factors that should be considered in determining the implementation of ramp signaling. Most of these are either non-engineering related or difficult to quantify, and include:

    - availability of alternative routes,
    - type of corridor where ramp signaling is being deployed,
    - public acceptance,
    - equity,
    - enforcement, and
    - funding.

CHAPTER 3
GUIDELINES EVALUATION AND SELECTION

This chapter consists of two major sections. The first section details the evaluation of the existing ramp signaling guidelines (in the form of warrants and criteria). The second section presents the guidelines for Florida applications. The justifications and reasoning behind the evaluation of the existing guidelines and selection of final guidelines for Florida are described in detail. The selected guidelines were implemented in the automated system described in the next two chapters.

3.1. Strategies of Warrant Selection

The purpose of identifying warrants is to provide a formatted set of criteria that can be applied in a variety of candidate ramp signaling cases to determine whether ramp signal deployment is appropriate. In this study, the adopted warrants will be implemented in a system integrated with multiple databases. Hence, potential warrants should not only be appropriate, but also objective and easy to apply. The following strategies are developed to guide the evaluation and recommendation of individual warrants:

- The adopted warrant should promote ramp signaling implementation to mitigate recurring congestion on freeway mainline, especially congestion caused by excessive platoons entering from on-ramp and attempting to merge with mainline traffic.

- The adopted warrant should promote ramp signaling implementation to address safety issue on freeway mainline, especially upstream of the candidate ramp and the vicinity of the merging area.

- The adopted warrant should aim to alleviate the negative impact that might be incurred by ramp signaling on the ramp as well as the adjacent road network.

- The recommended threshold value in an individual warrant should be based on extensive review of previous experiences or an analytical process.

- The adopted warrant should be, to the extent possible, objective and easy to apply.

The warrants evaluated in this study are grouped into three categories: Traffic, Geometric, and Safety.

3.2. Traffic Criteria

3.2.1. Mainline Volume

One of the goals of ramp signaling is to alleviate congestion on the mainline. Hence it is appropriate to set out warrants to justify ramp signaling when congestion on the mainline freeway is observed. One of the possible reasons for congestion is excessive demand entering the freeway. A number of agencies use mainline volume as a criterion to justify ramp signaling. These criteria are shown in Table 3-1.

Among these mainline volume criteria, some agencies utilize average volume over all the lanes, while others use only one or two rightmost lanes. All lane average volume reflects overall congestion on mainline freeway whereas right lane(s) average mostly represents congestion that might have been caused by inappropriate merging maneuver and/or excessive merging traffic. Based on FDOT ramp signal operation experience, ramp signals operate during peak hours with a goal of reducing the overall congestion on mainline freeway, especially that is caused by bottleneck(s). Hence the overall average mainline volume in the peak hour is recommended when an individual ramp signaling warrant on mainline volume is proposed.

Table 3-1 List of Ramp Signaling Warrants – Mainline Volume

Agency/State/Country	Criteria Description	Threshold (vphpl)
Minnesota	Mainline Volume	1,200 ~ 1,500
Texas	Two Right Lanes	>1,600*
Washington	Mainline Volume	>1,500
Wisconsin	Mainline Volume	>1,200
Australia	Mainline Volume	>1,700
U.K.	Upstream Mainline Volume	1,333 ~ 1,667**

*length of acceleration lane ≤ 500 feet; threshold increases when length of acceleration lane increases
**average value calculated based on original criteria

3.2.2. V/C Ratio

Volume to capacity (V/C) ratio is defined as the ratio of flow rate to capacity for a transportation facility, which also indicates congestion on the freeway. California and Wisconsin utilize V/C ratio as one of their criteria in warranting ramp signaling (Table 3-2). Wisconsin State Wide Ramp Control Plan states that "it is common practice to begin (ramp) metering when the freeway reaches a V/C ratio value of 0.7". California established a similar criterion with threshold values of 0.6 and 0.8. Some other studies show that a V/C ratio of 0.7 indicates congestion level transition from moderate to critical because incident rate starts to increase and traffic starts to breakdown (Chang et al., 2000).

Table 3-2 List of Ramp Signaling Warrants – V/C Ratio

Agency/State/Country	V/C Threshold
California	0.6 (initial) and 0.8 (further analysis)
Wisconsin	0.7

V/C ratio and mainline volume represent similar information from the perspective of ramp signaling warrants. If V/C ratio threshold values are converted into volume, the corresponding average mainline volume threshold value ranges from 1,200 to 1,600 vphpl, assuming a capacity of 2,000 vphpl. This range is very close to the range identified by volume threshold in the previous section. This study recommends peak hour mainline volume as an individual ramp signaling warrant and V/C ratio is not included to avoid redundancy.

3.2.3. Mainline Speed

Another common indicator of congestion is mainline speed. Ramp signaling should be considered when mainline speeds on urban freeways drop below the desirable levels. The definition of “desirable levels” is generally based on the agency’s goals and local travelers’ expectations. It was found that mainline speed is one of the most commonly used ramp signaling warrants. Table 3-3 shows the threshold values and the description of the warrants in terms of mainline speed established by different agencies.

Table 3-3 List of Ramp Signaling Warrants – Mainline Speed

Agency/State/ Country	Criteria Description	Threshold (mph)
MUTCD	Speed < threshold for duration of at least half an hour	50
Arizona	Speed < threshold for duration of at least 30 minutes for 200 or more calendar days per year	50
California	Average Mainline Speed <	30
Minnesota	Peak Period Speed <	30
Nevada	Mainline Speed constantly < 50 mph or Peak Period Speed < 40 mph	40, 50
Texas	Peak Period Speed <	50
Virginia	Peak Period Speed <	30
Wisconsin	Peak Period Speed <	30
U.K.	Peak Period Speed <	43.5*
Enterprise	Speed < threshold for duration of at least 30 minutes for 200 or more calendar days per year	50

*converted from 70kph

From Table 3-3, it can be seen that the speed threshold ranges from 30 to 50 mph. FDOT turns on ramp signals when mainline speed drops below 45 mph (FDOT, 2011). This operational strategy had been implemented since the activation of FDOT’s ramp signal system, and the overall performance of ramp signal is satisfactory. If 45 mph is considered as a threshold value to trigger a ramp signal, the criteria for ramp signaling should be higher and closer to 45 mph. Based on the literature review and in conjunction with the operational experience of FDOT, a peak hour speed of 50 mph is the ramp signaling warrant recommended in this study.

3.2.4. Level of Service (LOS)

Level of Service (LOS) is a qualitative measure describing operational conditions within a traffic stream. Freeway LOS is another good indicator of the congestion level on a freeway section. Lower LOS suggests a problem and may in part be due to the traffic from one or more on-ramps entering the freeway in platoons or because the overall demand on the freeway exceeds its capacity. Freeway conditions approaching LOS D or worse could be the candidates for ramp signaling, depending on other existing problems and appropriateness of other ramp management strategies in resolving problems. Table 3-4 shows the existing warrants based on LOS.

Table 3-4 List of Ramp Signaling Warrants – Freeway LOS

Agency/State/Country	Criteria Description	Threshold
Nevada	Freeway operates on or below a LOS of	D
New York	Freeway operates below a LOS of	D
Virginia	Freeway operates on or below a LOS of	E

Only few agencies have used LOS as a criterion to warrant the deployment of ramp signals. This is because substantial amount of data are required to calculate LOS. For instance, to calculate the LOS of a freeway segment, both geometric data (e.g., lane width, interchange density and lateral clearance, etc) and traffic data (e.g., free flow speed and demand volume, etc.) are needed. Incorporating LOS as an individual ramp signaling warrant in a set of criteria might require extensive data collection. Therefore, in this study, LOS is not recommended as a ramp signaling warrant.

3.2.5. Occupancy/Density

Both occupancy and density measure traffic intensity. Occupancy measures temporal concentration of traffic while density scales spatially. Occupancy data can often be collected from detectors and is calculated as the ratio of the time the detector is occupied to the total time that the detector is available. Density is defined as the number of vehicles on a roadway segment averaged over space, usually expressed as vehicles per mile per lane (vpmpl).

There are very few agencies considering occupancy or density as one of their criteria to warrant the deployment of ramp signals. For instance, New York State Highway Design Manual recommend that ramp signaling should be considered when traffic density exceeds 25 ~ 30 vehicle per kilometer per lane. WisDOT uses freeway occupancy of 20% as a threshold to determine if ramp signal should be turned on. WisDOT recommends using ramp signals when the freeway occupancy is greater than 18%.

Occupancy and density measure traffic intensity, which is highly related to congestion. However, the literature review showed that most of agencies utilize occupancy or density as one of the criteria to operate ramp signals (e.g., turning on/off ramp signal). They are not selected in this study as a condition to warrant ramp signaling implementation.

3.2.6. Ramp Volume

One of the goals of ramp signal installation is to mitigate congestion that is caused by excessive traffic entering from on-ramp and attempting to merge with the mainline traffic flow. Hence the establishment of ramp signaling warrant should consider ramp volume. First, ramp signal should be warranted only when the ramp volume is high enough for it to have an impact on the mainline traffic. If the ramp flow is lower than the minimum threshold, its interaction is unlikely to cause flow breakdown on the mainline freeway. Thus, there should be a minimum volume requirement to justify a ramp signal installation. On the other hand, the ramp volume cannot be too high as ramp signaling reduces ramp capacity. If the ramp demand exceeds the capacity after ramp signaling, the queuing traffic will spill back to the adjacent arterials, which is contradicted to the strategies identified in Section 3.1. Thus, there should be a maximum threshold value to prevent excessive queuing and spillover.

Ramp volume at peak period is one of the most widely used ramp signaling warrants. Most of the agencies provide an individual criterion employing ramp volume when a set of these criteria are setup. Table 3-5 lists these quantified ramp signaling warrants based on ramp volume. From Table 3-5, it can be seen that most of the agencies will consider ramp signaling when on-ramp volume is between 240 and 1,100 vph for signal lane ramp. A range of 240 ~ 900 vph is mostly recommended. When there are two or more lanes on the ramp, ramp signal implementation may be justified if the ramp volume is between 400 and 1,900 vph.

Table 3-5 List of Ramp Signaling Warrants – Ramp Volume

Agency/State/Country	Criteria Description	Threshold (vph)	
		Min	Max
California	For a one lane ramp	240	900
	For a two lane ramp	500	900
Colorado	For a one lane ramp	-	900
	For a two lane ramp	900	-
Nevada	For a one lane ramp	-	1,100
	For a two lane ramp	1,200	1,900
New York	For a one lane ramp	240	900
	For a two lane ramp	400	1,800
Oregon	For a one lane ramp	240	900
	For a two lane ramp	-	1,650
Texas	Ramp signaling should be considered when	300	-
Utah	For a one lane ramp	180	900
	For a two lane ramp	600	1,350
	For a three Lane ramp	1,080	1,720
Wisconsin	For a one lane ramp	240	-
	For a two lane ramp	400	-
U.K.	For a one lane ramp	400	900
	For a two lane ramp*	800	1,800
Enterprise	For a one lane ramp	240	900
	For a two lane ramp*	480	1,800

*original threshold value for this criterion is measured by vphpl

The selection of higher boundary of ramp volume depends on the capacity of a ramp after ramp signaling. *Ramp Management and Control Handbook* (Jacobson et al., 2006) provides the capacity of ramp signaling with different flow control strategies (Table 2-1). The capacity of a single-lane ramp with ramp signaling is 1,200 vph and the capacity is 1,700 vph if there are multiple lanes. In the ramp signaling system implemented by FDOT along I-95 in Miami-Dade County, there is one ramp signal site with a varying number of lanes (can be considered as multiple lanes) along the ramp that have a peak-hour ramp volume greater than 1,700 vph. This ramp is from Ives Dairy Road to northbound I-95 (peak hour volume 1,770 vph). The initial operation test showed that excessive queuing was observed if this signal operates daily during peak periods. The current operation strategy is for this ramp to be turned on only when there is non-recurring congestion (i.e., congestion caused by an incident) downstream of these ramps. Based on the literature and the experience from FDOT, the following ramp signaling warrants are recommended:

- For a ramp with a single lane, ramp signaling is considered when the on-ramp volume is between 240 and 1,200 vph.
- For a ramp with multiple lanes, ramp signaling is considered when the on-ramp volume is between 400 and 1,700 vph.

3.2.7. Mainline and Ramp Volume

A number of agencies established ramp signaling warrant utilizing the summation of mainline and on-ramp volumes. The basis of this warrant is obtained from the concept of "merging volume". This warrant is developed based on the assumption that a ramp signal implementation is more likely to be justified when the "merging volume" is high. The merging volume is the combination of the ramp volume entering the freeway and the mainline volume. If the merging volume is too high, traffic flow breakdown will occur in the vicinity of the merging area. Ramp signaling regulates traffic entering into mainline freeway by breaking the platoons, thus have a potential to address the issue.

Among the warrants that consider merging volume, some use volume on all the mainline lanes (Table 3-6), while others depend on volume on the rightmost lanes (Table 3-7). From Table 3-6, all agencies have used the same threshold values while considering volume over all lanes. The following warrant is recommended in this study based on the most used threshold values: a ramp signaling implementation should be considered when the mainline peak hour volume (all lanes combined) plus ramp peak hour volume is greater than the threshold depending on the total number of lanes, specifically:

- If there are two lanes, warrant is met when total volume is greater than 2,650 vph
- If there are three lanes, warrant is met when total volume is greater than 4,250 vph
- If there are four lanes, warrant is met when total volume is greater than 5,850 vph
- If there are five lanes, warrant is met when total volume is greater than 7,450 vph
- If there are six lanes, warrant is met when total volume is greater than 9,050 vph
- If there are more than six lanes, warrant is met when total volume is greater than 10,650 vph

Note that the total number of lanes is the number of mainline lanes in one direction including auxiliary lanes that continue at least 1/3 mile downstream from ramp gore.

Table 3-7 lists the threshold value when only the rightmost lane is considered. Only the rightmost lane is considered because it is most likely to be affected by the merging traffic entering from on-ramp. Three agencies had setup a critical value while using this criterion. Texas warrant also considers the length of acceleration lane while applying this warrant. The average value of these three thresholds is 2,067 vph. A critical value of 2,050 vph is recommended in this study.

Table 3-6 List of Ramp Signaling Warrants – Mainline plus Ramp Volume

Agency/State/Country	Ramp Signal should be considered when > Threshold	
	# of Mainline Lanes	Threshold (vph)
Arizona	2	2,650
	3	4,250
	4	5,850
	5	7,450
	6	9,050
Colorado	2	2,650
	3	4,250
	4	5,850
Utah	2	2,650
	3	4,250
	4	5,850
	5	7,450
	6	9,050
	7	10,650
Enterprise	2	2,650
	3	4,250
	4	5,850
	5	7,450
	6	9,050

Table 3-7 List of Ramp Signaling Warrants – Mainline Right Lane(s) plus Ramp Volume

Agency/State/Country	Threshold (vph)
Arizona	2,100
California	1,800
Texas	2,300*

*Length of acceleration lane ≤ 500 feet; the threshold increases when length of acceleration lane increases

3.3. Geometric Criteria

3.3.1. Ramp Storage

One of the strategies of developing ramp signaling warrants is that "the adopted warrant should aim to prevent the negative impact that may be incurred by ramp signaling on the ramp as well as the adjacent road network". The working principle of ramp signaling is to control the discharge of traffic from the ramp to reduce the interference of merging traffic on the mainline freeway. There is a risk that the queuing on ramp may extend onto the adjacent intersection. This warrant strives to prevent this problem. Queue length on ramp depends on the demand and discharge rate, as well as the available storage space. From the literature review, it is found that a great number of agencies have used ramp storage capacity to warrant ramp signaling. The idea is that ramp signaling should only be justified when there is adequate storage on ramp.

Most of the agencies presented qualitative warrants pertaining to ramp storage capacity, while a few agencies provided quantified criterion. Among these quantified methods, following are the three types of mostly used warrants:

- *A fixed minimum ramp length:* Ramp signaling should only be warranted if the existing ramp storage distance is longer than a minimum threshold.
- *10% peak hour volume warrant:* Ramp signaling should only be warranted when the ramp can provide storage space to accommodate 10% of pre-signaling peak hour volume.
- *Queue estimation warrant:* Ramp signaling should only be warranted when the ramp storage distance exceeds a queuing length, estimated using a formula based on the traffic demand input.

The fixed value method is used by New Zealand and U.K. Table 3-8 lists the minimum length required by the warrant. The fixed value method is simple, however not robust. The buildup queue length depends on ramp demand, which varies from ramp to ramp, and from one geographic location to another. For this reason, this method is not recommended in this study.

Table 3-8 List of Ramp Signaling Warrants – Minimum Ramp Storage Requirement

Agency/State/Country	Threshold (meters)
New Zealand	120
U.K.	300

A 10% peak hour volume warrant is being used by several states in the U.S. including Nevada, New York, and Wisconsin. It is fairly easy to apply. Once the pre-signaling peak hour volume is calculated, the required storage distance could be calculated by multiplying the vehicle storage requirement (i.e., 10% of peak volume) by the average assumed vehicle length (i.e., 25 feet), as follows:

$$L = 0.1V \times a \qquad (3\text{-}1)$$

The queue estimation warrant use similar principle as the 10% peak hour volume warrant. However, instead of using a simple 10% multiplier, queue estimation warrant uses a formula to estimate the required ramp storage space as a function of ramp demand. TTI uses the following spacing model to determine the ramp storage requirement for a single-lane ramp:

$$L = 0.25V - 0.00007422V^2 \qquad (3\text{-}2)$$

where,

L = required single-lane storage distance (meter), and
V = peak hour ramp demand (vph).

To evaluate the effect of these two methods, the existing 22 ramp signaling sites along I-95 implemented by FDOT D6 in Miami-Dade County were examined (see ramp locations in Figure 3-1).

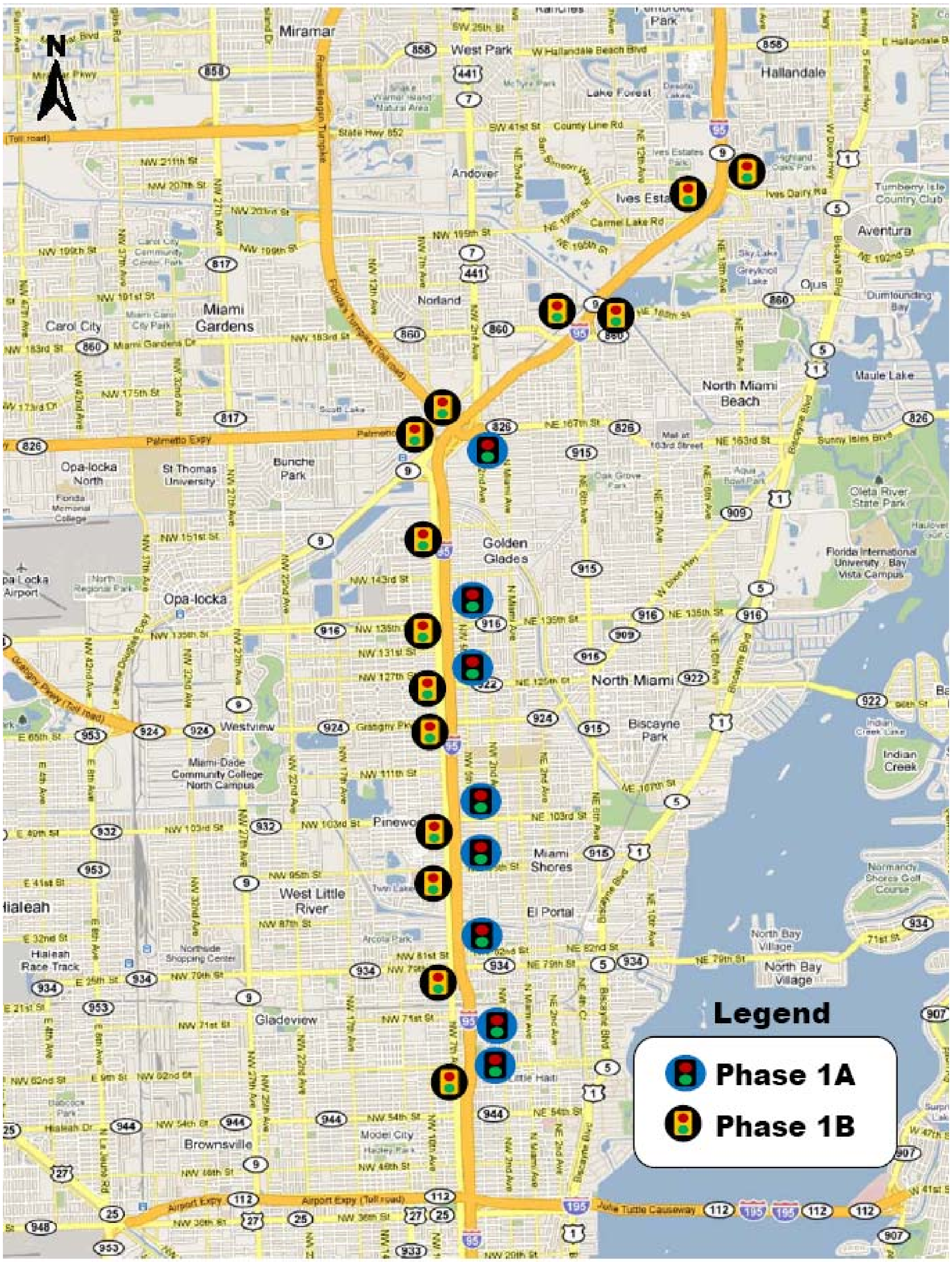


Figure 3-1 Ramp Signal Locations on I-95 Implemented by FDOT D6

Table 3-9 shows the results. From Table 3-9, ramp signaling is not warranted at any of the existing 22 sites as per the 10% peak volume criterion. The result indicates that excessive spillback might occur since the available storage length is less than the required space predicted by the 10% warrant. Based on FDOT's experience, these 22 ramp sites have been operating acceptably without excessive spillback onto the adjacent arterial intersections. By using the queue estimation method, ramp signaling is warranted on all the ramp signaling sites, which is consistent with the current status of FDOT's observation. At ramp signaling sites 6, 7, and 21, the available storage length is slightly lower than the predicted required space, consistent with existing condition. In reality, these ramp sites are 100% occupied during peak period from time to time.

Table 3-9 Effect of Ramp Storage Warrant – 10% Method vs. Queue Estimation Method

Ramp Site	Peak Hour Volume (vph)	Available Storage Length L (ft)*	Queue Estimation Method		10% Peak Volume Method	
			Required Space (ft)	Warranted?	Required Space (ft)	Warranted?
1	910	1,276	545	Yes	2,275	No
2	294	307	220	Yes	735	No
3	913	866	546	Yes	2,283	No
4	494	689	346	Yes	1,235	No
5	560	846	383	Yes	1,400	No
6	879	582	533	Yes	2,198	No
7	847	610	520	Yes	2,118	No
8	888	1,614	536	Yes	2,220	No
9	1,049	2,858	592	Yes	2,623	No
10	1,772	6,155	689	Yes	4,430	No
11	1,540	4,585	686	Yes	3,850	No
12	947	2,465	558	Yes	2,368	No
13	935	1,725	554	Yes	2,338	No
14	398	547	288	Yes	995	No
15	354	930	260	Yes	885	No
16	714	925	461	Yes	1,785	No
17	579	916	393	Yes	1,448	No
18	836	974	516	Yes	2,090	No
19	762	976	484	Yes	1,905	No
20	817	1,070	508	Yes	2,043	No
21	1,082	607	602	Yes	2,705	No
22	667	668	439	Yes	1,668	No

*$L=L_1+2L_2+3L_3$, L_1 = Length of segment with one lane; L_2 = Length of segment with two lanes; L_3 = Length of segment with three lanes.

Based on the evaluation results, 10% peak volume criterion seems to provide a very "over-strict" warrant that may exclude a ramp signaling site that might need ramp signaling. This warrant is, thus, not recommended. Instead, the queue estimation method is recommended since it provides a moderate estimation of the required space, therefore, more suitable in ramp signaling site selection.

3.3.2. Length of Acceleration Lane

One of the most important perspectives of developing ramp signaling warrant is that such warrant, if applied, should strive to prevent any potential safety concerns that might be incurred by ramp signaling implementation. In other words, a warrant should not justify ramp signaling if potential safety concern may arise due to ramp signaling implementation.

The working principle of ramp signaling requires a vehicle to come to a full or near full stop before the stop bar prior to entering mainline freeway. After released by the ramp signal, the vehicle needs to speed up and merge into mainline traffic using acceleration lane (see Figure 3-2). In reality, this acceleration distance might be limited. Thus, a warrant should be established to ensure that the distance downstream of the ramp signal is adequate to permit vehicles to accelerate to the mainline freeway prevailing speeds.

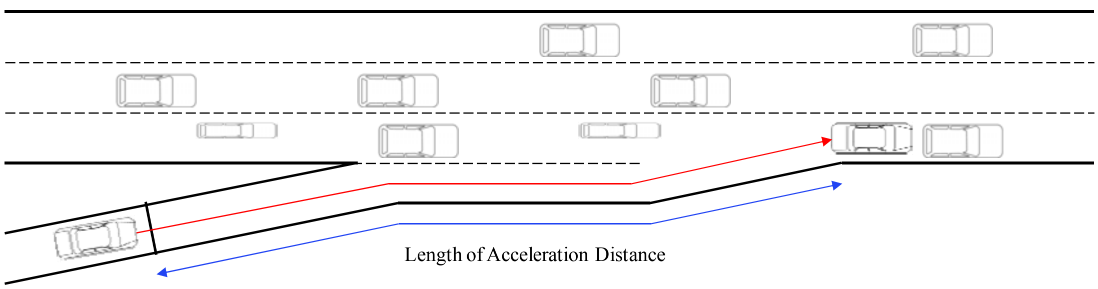


Figure 3-2 Vehicle Accelerating onto the Freeway Mainline after Released by the Ramp Signal

If acceleration distance is inadequate, safety along the ramp, freeway, or at the merging area may be jeopardized. Vehicles entering the freeway at speeds lower than the prevailing mainline speeds might force vehicles approaching the freeway/ramp merge point to slow down or change lanes to allow vehicles from the ramp to enter safely. This will increase the likelihood of rear-end and sideswipe collisions at locations immediately upstream of the freeway/ramp merge point. Also, slow moving vehicles entering from a ramp might be forced to wait for gaps in mainline traffic at the freeway/ramp merge point before entering the freeway facility. This action might result in increased sideswipe collisions at the freeway/ramp merge point as well as rear-end collisions on the ramp.

Several methods have been employed to provide a minimum acceleration or merging distance needed to justify ramp signaling. These include:

- *Using a fixed minimum acceleration distance:* Ramp signaling should only be warranted if the existing acceleration distance is longer than the minimum threshold.
- *Green Book Method:* Minimum acceleration distance is determined using AASHTO Green Book (AASHTO, 2004).
- *Time to Collision (TTC) Method:* Minimum acceleration distance is calculated using the ramp vehicle's minimum speed requirement at the merging area. This minimum speed is determined by a selected TTC (Refer to Section 2.3.9).

Presence of acceleration lane of a fixed length of 205 meters (672 feet) was used by the U.K. as a ramp signaling warrant. It is fairly straightforward, but not robust enough to be applied in the U.S. The minimum acceleration distance highly depends on the prevailing speed on mainline highway and should vary based on the speed requirement.

A number of agencies referenced AASHTO Green Book while determining the minimum required merging/ acceleration distance. Minimum acceleration distances for entrance terminals with flat grades of 2 percent or less as presented in the Green Book (2004) are shown in Figure 3-3. AASHTO Green book provides a list of minimum acceleration distances based on vehicle initial speed and the speed that needs to be reached after acceleration. This table was originally used for ramp design.

US Customary										
		Acceleration length, L (ft) for entrance curve design speed (mph)								
Highway		Stop condition	15	20	25	30	35	40	45	50
		and initial speed, V'_a (mph)								
Design speed, V (mph)	Speed reached, V_a (mph)	0	14	18	22	26	30	36	40	44
30	23	180	140	–	–	–	–	–	–	–
35	27	280	220	160	–	–	–	–	–	–
40	31	360	300	270	210	120	–	–	–	–
45	35	560	490	440	380	280	160	–	–	–
50	39	720	660	610	550	450	350	130	–	–
55	43	960	900	810	780	670	550	320	150	–
60	47	1200	1140	1100	1020	910	800	550	420	180
65	50	1410	1350	1310	1220	1120	1000	770	600	370
70	53	1620	1560	1520	1420	1350	1230	1000	820	580
75	55	1790	1730	1630	1580	1510	1420	1160	1040	780
Note: Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 1,300 ft.										

Figure 3-3 Minimum Acceleration Distances for Entrance Terminals with Flat Grades of 2 Percent or Less (AASHTO, 2004)

When applying this table in ramp signaling warrant, the worst case scenario is when the vehicle starts from a full stop (initial speed is 0 mph) and accelerates to the prevailing mainline speed. Plotting the relation between the required acceleration distance (L) and the speed to be reached, a curve is established to determine the minimum acceleration distance per given freeway merging or prevailing speed (see Figure 3-4).

The following mathematical relation between minimum acceleration distance and the freeway mainline prevailing speed can be established by curve fitting using data in Figure 3-4:

$$L=0.3987V^2 - 26.62V + 267 \quad (3\text{-}3)$$

where,

L = required minimum acceleration distance (feet), and
V = freeway mainline prevailing speed (mph).

Note that the prevailing freeway speed should be the existing speed in place during ramp signaling operations, and not freeway design speed or free flow speed. Based on FDOT's experience, the prevailing mainline speed during ramp signal operation can be relatively low since ramp signals only operate during peak hours. For example, FDOT has chosen a 45 mph as a trigger to turn on ramp signals.

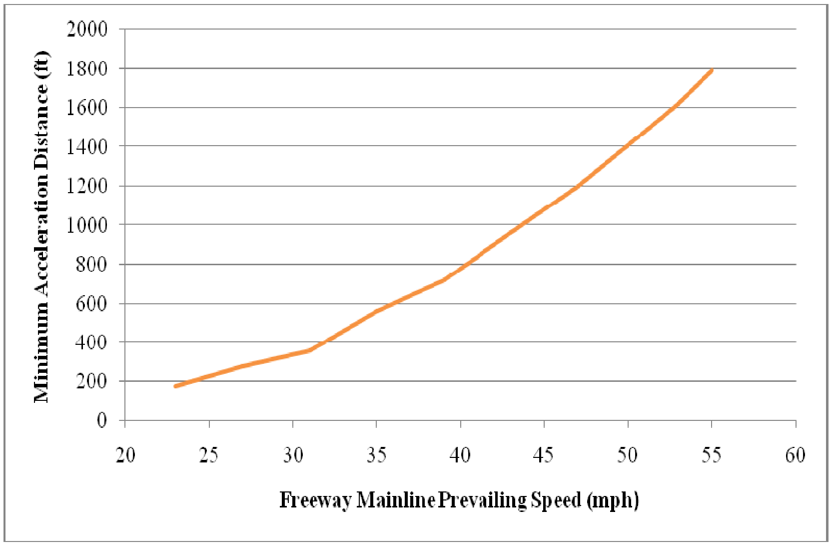


Figure 3-4 Minimum Acceleration Distance based on Merging Speed (AASHTO, 2004)

TTC method was developed by Texas Transportation Institute (TTI) as an attempt to establish ramp signaling warrants for TxDOT. This method assumes that the interacting ramp and freeway traffic vehicles must be able to maintain a desirable time to collision (TTC) after the merge. A TTC value lower than a specified threshold indicates an unsafe merging condition at the freeway/ramp merge point. Specific details of this warrant are described in Section 2.3.9. Table 2-4 provides the minimum speed required to ensure safe merging by a given FFS (this method use FFS as the "prevailing speed" that a vehicle needs to reach) and a selected TTC. Once a minimum speed is identified, based on kinematics, the minimum sufficient acceleration distance for the ramp vehicle can be calculated using the following formula:

$$L = 1.076 \frac{V^2}{a} \tag{3-4}$$

where,

L = required minimum acceleration distance (feet),
V = minimum speed required to ensure safe merging by a given TTC (vph), and
a = acceleration rate (ft/s^2), assuming 3.22 ft/s^2

Using values provided in Table 2-4 and Equation 3-4, a graph is plotted (as shown in Figure 3-5) to depict the relation between freeway mainline prevailing speed and required minimum acceleration distance. Figure 3-6 shows the process of curve fitting to identify formulae to depict the mapping between the two variables. Formulae 3-5, 3-6, and 3-7 are established:

TTC =1.5 s $L=0.14V^2+2.95V+12.80$ (3-5)
TTC =1.75 s $L=0.14V^2+3.00V+9.21$ (3-6)
TTC =2.0 s $L=0.14V^2+2.12V - 0.78$ (3-7)

where,

L = required minimum acceleration distance (feet), and
V = freeway mainline prevailing speed (mph).

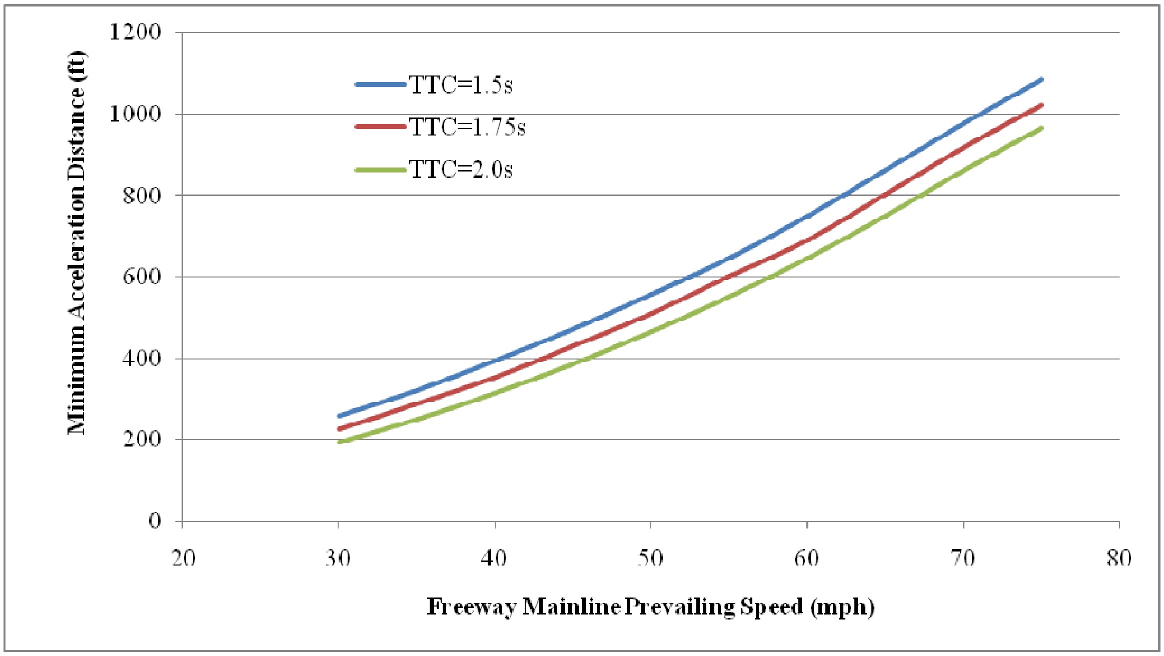


Figure 3-5 Minimum Acceleration Distance based on Merging Speed – TTC Method

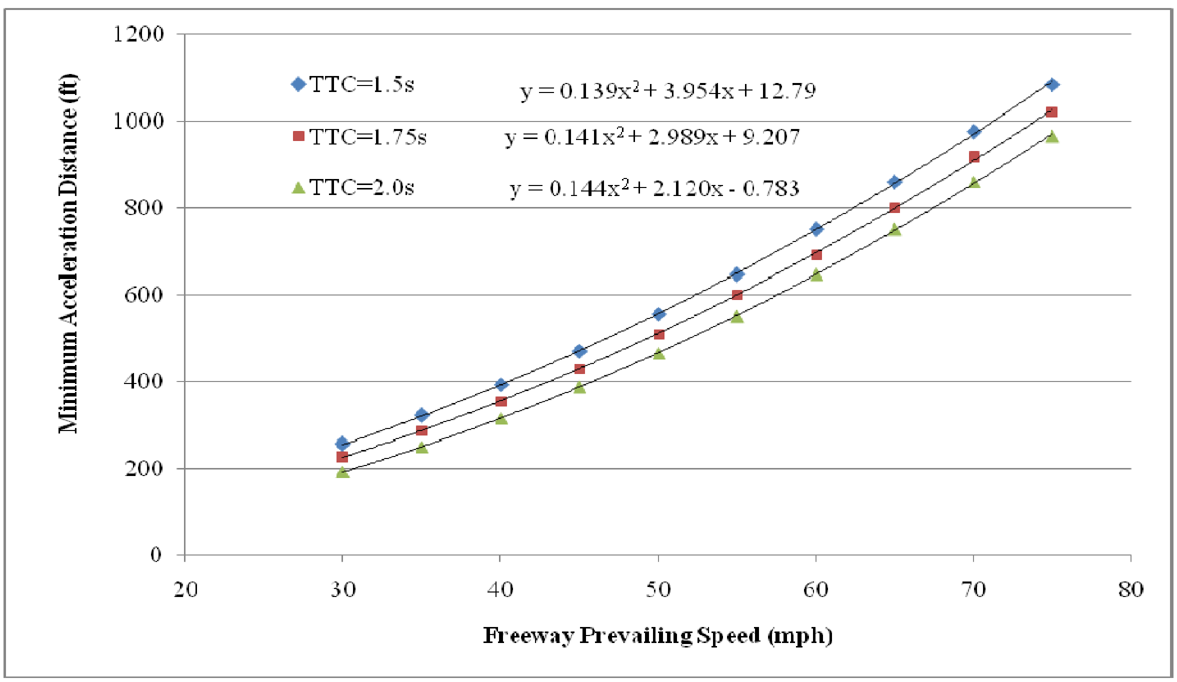


Figure 3-6 Curve Fitting for TTC Method

Table 3-10 shows the required minimum acceleration distance obtained by applying the three different methods for varying prevailing mainline speeds. AASHTO method generally provides higher required minimum acceleration distance than TTC method for a given speed, indicating that AASHTO method is more conservative than TTC method.

Table 3-10 Minimum Acceleration Distance Required for Fixed Length, AASHTO, and TTC Methods

Prevailing Mainline Speed (mph)	Minimum Acceleration Distance Required (ft)				
	Fixed Length Method	AASHTO Method	TTC Method		
			TTC = 1.5 s	TTC = 1.75 s	TTC = 2.0 s
25	672	218	122	95	63
30	672	357	258	226	194
35	672	544	322	287	251
40	672	782	393	354	315
45	672	1,068	472	429	387
50	672	1,404	557	511	466
55	672	1,789	647	600	551
60	672	2,223	750	692	647
65	672	2,707	862	802	750
70	672	3,240	978	917	862

FDOT has chosen 45 mph as a trigger to turn on ramp signals. The prevailing mainline speed during ramp signal operation is generally lower than 45 since ramp signals only operate during peak hours. Table 3-11 shows the results of applying three different methods to warrant FDOT's 22 ramp signals assuming a 45 mph prevailing freeway mainline speed. The AASHTO method appears to be stricter, disqualifying half of the ramp signals currently operating acceptably in terms of merging. The TTC method is recommended based on these evaluation results.

3.4. Safety Criteria

Literature shows that safety is a major potential benefit of ramp signaling, mainly through reducing the number of crashes in the acceleration lanes and merging areas. It is therefore reasonable to establish a warrant to justify ramp signaling when there is a safety concern. Safety concern is so important that it alone could be sufficient to justify installation of ramp signaling, regardless of the traffic and geometric criteria. To address the safety criteria, crash rate has been widely used by states/agencies in their ramp signaling justifications. These states include, but are not limited to, Arizona, California, Colorado, Minnesota, Nevada, Texas, Virginia, Washington, and Wisconsin. It was consistently agreed that ramp signaling should be warranted when there is a high frequency of crashes (i.e., when collision rate exceeds the acceptable rate within the subject metropolitan area) near freeway entrances due to platooning of on-ramp traffic, inadequate merge area, and/or congestion.

Despite the popularity of using crash rate in ramp signaling justification, none of the agencies/states have explicit threshold limits in terms of crash rate for implementing ramp signaling except for WisDOT. WisDOT employs RHMVM, Crash rate per hundred million vehicle-miles to measure potential safety concern; RHMVM is a statistic commonly used to identify locations with abnormally high crash rate, and it is calculated using the following formula:

$$\text{RHMVM} = \frac{\text{Number of Crashes} \times 100{,}000{,}000}{\text{AADT} \times 365 \times \text{Distance}} \tag{3-8}$$

Table 3-11 Application of Minimum Acceleration Distance Warrants on FDOT's System

Ramp Site	Available Acceleration Distance L (ft)	Ramp Signaling Warranted?				
		Fixed Length Method	AASHTO Method	TTC Method		
				TTC = 1.5s	TTC = 1.75s	TTC = 2.0s
1	993	Yes	No	Yes	Yes	Yes
2	966	Yes	No	Yes	Yes	Yes
3	995	Yes	No	Yes	Yes	Yes
4	972	Yes	No	Yes	Yes	Yes
5	1,327	Yes	Yes	Yes	Yes	Yes
6	1,683	Yes	Yes	Yes	Yes	Yes
7	2,920	Yes	Yes	Yes	Yes	Yes
8	570	No	No	Yes	Yes	Yes
9	470	No	No	No	Yes	Yes
10	4,553	Yes	Yes	Yes	Yes	Yes
11	846	Yes	No	Yes	Yes	Yes
12	1,365	Yes	Yes	Yes	Yes	Yes
13	1,019	Yes	Yes	Yes	Yes	Yes
14	653	No	No	Yes	Yes	Yes
15	1,964	Yes	Yes	Yes	Yes	Yes
16	1,633	Yes	Yes	Yes	Yes	Yes
17	875	Yes	No	Yes	Yes	Yes
18	844	Yes	No	Yes	Yes	Yes
19	877	Yes	No	Yes	Yes	Yes
20	1,190	Yes	Yes	Yes	Yes	Yes
21	2,241	Yes	Yes	Yes	Yes	Yes
22	> 5,000	Yes	Yes	Yes	Yes	Yes

where,

RHMVM = crash rate per hundred million vehicle-miles,
AADT = Average Annual Daily Traffic on the facility (vpd), and
Distance = length of roadway segment (mile).

A threshold of 80 crashes per hundred million vehicle miles was selected by WisDOT in warranting ramp signaling installation. It means that a ramp signal should be implemented if the facility or roadway segment has a crash rate > 80 crashes per hundred million vehicle miles. This is recommended in this study.

3.5. Recommended Individual Warrants

This section lists the warrants recommended in Chapter 3. The warrants are categorized into traffic criteria, geometric criteria, and safety criteria, and include:

- *Warrant 1- Mainline Volume:* Ramp signaling is warranted at a location where the overall average mainline volume during the peak hour is greater than 1,200 vphpl.

- *Warrant 2- Mainline Speed:* Ramp signaling is warranted at a location where the average mainline speed during the peak hour is less than 50 mph.

- *Warrant 3- Ramp Volume:* Ramp signaling is warranted at a location if the following conditions are met:

  a) For a ramp with a single lane, ramp signaling is considered when the peak hour on-ramp volume is between 240 and 1,200 vph.
  b) For a ramp with multiple lanes, ramp signaling is considered when the peak hour on-ramp volume is between 400 and 1,700 vph.

- *Warrant 4- Total Mainline and Ramp Volume:* Ramp signaling is warranted when any of the following conditions is met:

  Condition 1: The summation of peak hour mainline volume and ramp volume exceeds the following threshold values:

  a) If there are two lanes, warrant is met when total volume is greater than 2,650 vph
  b) If there are three lanes, warrant is met when total volume is greater than 4,250 vph
  c) If there are four lanes, warrant is met when total volume is greater than 5,850 vph
  d) If there are five lanes, warrant is met when total volume is greater than 7,450 vph
  e) If there are six lanes, warrant is met when total volume is greater than 9,050 vph
  f) If there are more than six lanes, warrant is met when total volume is greater than 10,650 vph

  Note that the total number of lanes is the number of mainline lanes in one direction including auxiliary lanes that continue at least 1/3 mile downstream from ramp gore.

  Condition 2: Peak hour volume of the rightmost lane exceeds 2,050 vph.

- *Warrant 5- Ramp Storage:* Ramp signaling is warranted at a location where the ramp storage distance is longer than the queuing length estimated by the following equation:

$$L=0.25V - 0.00007422V^2 \tag{3-9}$$

  where,

  L = required single-lane storage distance (meter), and
  V = peak hour ramp demand (vph).

- *Warrant 6- Acceleration Distance:* Ramp signaling is warranted at a location where the acceleration distance after the stop bar is longer than the required safe merging distance estimated by the following equation:

$$L=0.14V^2+3.00V+9.21 \tag{3-10}$$

  where,

  L = required minimum acceleration distance (feet), and
  V = freeway mainline prevailing speed (mph).

- *Warrant 7- Crash Rate:* Ramp signaling is warranted at a location where the facility or roadway segment has a crash rate of over 80 crashes per hundred million vehicle miles (HMVM). RHMVM is calculated using the following formula:

$$RHMVM = \frac{Number\ of\ Crashes\ per\ year \times 100{,}000{,}000}{AADT \times 365 \times Distance} \tag{3-11}$$

where,

RHMVM = crash rate per hundred million vehicle-miles,
AADT = Average Annual Daily Traffic on the facility (vpd), and
Distance = length of roadway segment (mile).

Note that warrants 1 through 6 can be used for an individual ramp location, whereas warrant 7 can only be applied to a facility or roadway segment with multiple ramps.

3.6. Signaling Warrant Process

Section 3.5 identified all the individual warrants recommended in this study. However, in most cases, not all warrants have to be met for justifying the installation of ramp signals. Certain warrants have higher priority than others in justifying ramp signalization (e.g., safety concerns). Therefore, ramp signaling could be deemed necessary by satisfying certain "high priority" criterion. To address these issues, a systematic methodology/process (typically formatted as a flow chart) is developed. The purpose of this process is to have a common formal procedure that can be applied in a variety of candidate ramp signaling cases to determine whether ramp signal deployment is appropriate. This procedure incorporates the individual warrants in a process that balance both qualitative and quantitative criteria. Figure 3-7 shows the flowchart of ramp signaling warrant procedure for planning purpose. This procedure can be applied to existing ramps that are being considered for ramp signaling.

3.7. Data Collection for Applying Warrants

To apply the procedure to determine whether ramp signaling should be implemented, a variety of data needs to be collected. These include:

- Freeway mainline peak hour volume (vphpl)
- Freeway mainline peak hour speed (mph)
- Number of lanes on the ramp of interest
- Number of mainline lanes in one direction including auxiliary lanes that continue at least 1/3 mile downstream from ramp gore
- Ramp peak hour volume (vph)
- Freeway mainline rightmost lane peak hour volume (vph)
- Existing ramp storage distance from the bottom of the ramp to the location where stop bar and ramp signal will be placed (feet)
- Existing acceleration distance from the location where stop bar and ramp signal will be placed to the end of the acceleration lane (feet)
- Number of crashes per year over the segment of roadway along which ramp signaling is

considered

- Average Annual Daily Traffic on the facility or the segment of interest (vpd)
- Length of roadway segment of interest (mile)

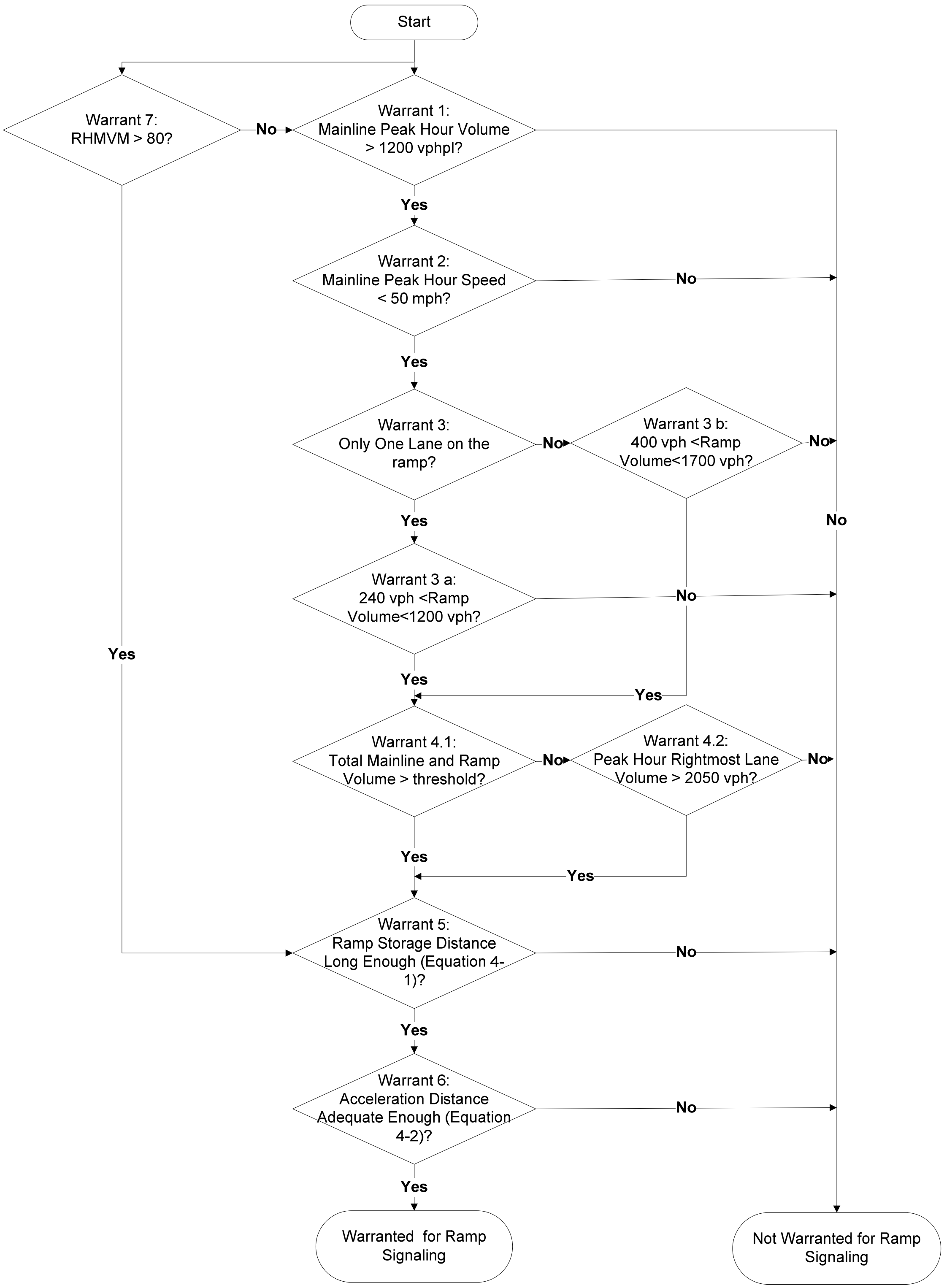


Figure 3-7 Ramp Signaling Procedures for Planning Purpose

CHAPTER 4
SYSTEM ARCHITECTURE AND DATABASE DEVELOPMENT

The chapter describes the design of Florida Highway Information System (FHIS), a web-based GIS system that was developed to automate the evaluation of ramp signaling using the guidelines selected in the previous chapter. It introduces a central database that integrates multiple existing databases from FDOT that currently operate independently. The user interface and the associated functions of the system are described in the next chapter.

4.1. System Architecture

Figure 4-1 shows the architecture of the system. It includes Microsoft's Internet Information Service (IIS), SQL Server 2008 database system, ESRI's ArcGIS Server, and SQL Server Reporting Services (SSRS). These components are deployed on Microsoft Windows Server 2008 and .NET framework to support the system data and GIS services. These components are briefly described below:

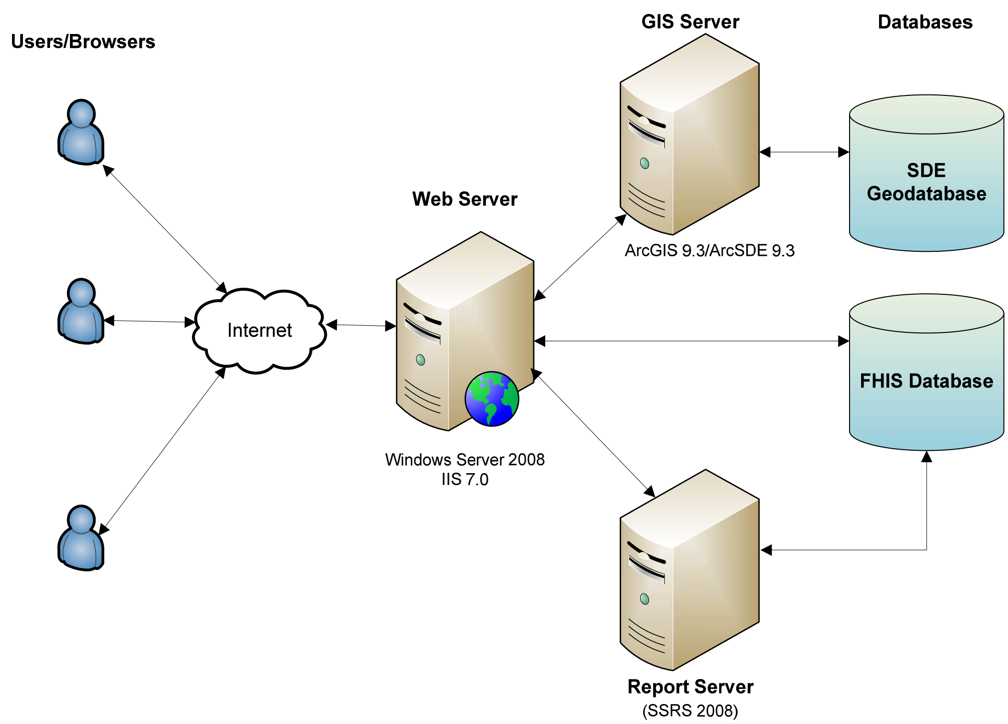


Figure 4-1 System Architecture

- *Web Browser*: A web browser is an increasingly popular choice of a user's interface. It allows the users to interact with the FHIS web pages to visualize the complex spatial GIS data and present highway transportation data results.

- *Web Server*: The web server in this architecture runs on Windows Server 2008, which is an Internet Information Services (IIS) 7.0 web server. The web application resides within this server to handle the Hypertext Transfer Protocol (HTTP) requests forwarded by the IIS web server.

- *GIS Server*: The system uses ESRI's ArcGIS Server to provide GIS data visualization, spatial data analysis, mapping, and spatial data management services. With a scalable GIS server platform, ArcGIS Server can be deployed on a single machine to support small workgroups, or can be distributed across multiple servers for supporting enterprise applications. With the ArcSDE as a data gateway, the ArcGIS Server can deploy a geodatabase which stores the GIS data inside the SQL Server database server.

- *Report Server*: SQL Server Reporting Services (SSRS) is a server-based reporting platform that works with Microsoft SQL Server and Microsoft Visual Studio .NET environment to create and view interactive, tabular, graphical, or free-form reports based on the query results selected within the FHIS system.

- *Database Server*: Microsoft SQL Server is a database management and analysis system for e-commerce, line-of-business, and data warehousing solutions. With the support of SQL Server 2008, several data including spatial GIS data, roadway data, incident data, crash data, traffic count data, and detector data are stored and managed efficiently. Both SDE geodatabase and FHIS traditional relational database provide data query and analysis services to the Web Server, GIS Server, and Report Server.

4.2. Databases

The database server of the system consists of two major databases: a geodatabase named SDE, and a traditional relational database named FHIS. The SDE database contains the spatial data while the FHIS database includes integrated roadway geometric data, incident records, crash records, traffic count data, and detector data. These data can also be classified into two groups: operational data and basemap data. The operational data is actively used in the web query and statistical analysis, while the basemap data are present within the application to support the operational data.

4.2.1. Major Data Tables

A data table is a conceptual representation of the data structures that are required by a database. As mentioned earlier, the system integrates data from five databases that are maintained and function independently. These data are integrated into five core data tables in the system's central database. These core data tables are consolidated based on 8-digit roadway number and milepost (for specific point locations, such as crash, incident, traffic count, and detector location), or 8-digit roadway number, begin milepost, and end milepost (for specific segment locations, such as RCI segment). The five core tables are briefly discussed below:

- *Crash data table*: The crash data are obtained from FDOT safety office. This table has all crashes that occurred on Florida state roadway system and includes crash location, time, roadway type, roadway condition, contributing cause, vehicle type, types of harmful events, etc.

- *RCI data table*: The Roadway Characteristics Inventory table mainly provides roadway geometric information including number of mainline lanes, lane width, acceleration lane width, shoulder width, grades, existence of frontage roads, speed limits, etc.

- *Detector data table*: Detector data are obtained from the STEWARD database system maintained by the University of Florida and is available at http://cdwserver.ce.ufl.edu/steward/. A tool was developed to query and extract the current traffic volume and speed data. Data for each station ID, the detector identifier associated to a roadway number and milepost, were incorporated into the FHIS detector data table.

- *Traffic count table*: Traffic count data including AADTs, truck factors, K factors, and D factors for portable and permanent traffic monitoring sites. These data for the 2000-2010 years were integrated into the FHIS database.

- *Incident data table*: Freeway incident data are available from the SunGuide incident database. Incidents are not initially associated to roadway number and milepost, the uniform location definition used inside the FHIS database system. A GIS linear reference approach is later used to identify the roadway number and milepost from the locations' coordinates.

4.2.2. Data Integration

As mentioned in the previous section, both raw detector data and incident data do not have associated roadway numbers and mileposts. To integrate these data and make sure each data record in the integrated five major data tables is available for data query and analysis, two tools were developed to associate a location to a roadway number and milepost:

1. *Conversion Tool for Incident Data*: Each freeway incident record has a pair of coordinates to represent the nearest spatial location. To convert the latitude/longitude data into roadway/milepost data, the conversion tool uses GIS technologies as described in the following steps:

    a) Create a 50 meter spatial buffer around the incident point based on its latitude/longitude values.
    b) Search state freeway road features that intersect with the created buffer. If none of the freeway road features intersect, then perform the search by expanding the buffer size to 100 meters.
    c) Examine the roadway features identified within the buffer zone and select the roadways with the same route numbers as the route number of the incident. For example, the incident location description with a route number of 826 results in selecting SR 826 road segments.
    d) When several roadway features exist within the buffer, only the roadway nearest to the incident point is stored.
    e) The perpendicular dropped from the incident point to the roadway segment gives the intersection point of the incident and the roadway network. This intersection point is used to identify the road segment which has roadway number, begin milepost, and end milepost.
    f) Linear reference method was used to calculate the relative location of the intersection point on the road segment, thus estimating the milepost of the incident location on the road segment.

2. *Conversion Tool for Detector Dat*a: The detector data stored in the current FHIS database system were downloaded from the STEWARD database system. In the STEWARD web site, users can select various attributes of detector data including the start date, end date, time range, aggregation level, facility, direction, and stations/detectors. The data reports can be retrieved from the aggregated data in the 5-minute, 15-minute, and 1-hour resolutions (Courage and Lee, 2009). However, the detector location obtained from the STEWARD database system is represented by three columns: STATION_ID, STATION_DESC, and STATION_MP. Table 4-1 shows sample detector locations along the I-95 in Broward County. The STATION_MP is the state milepost of the detector along the freeway facility, i.e., I-95, which is continually from zero to the length of the entire I-95 within the state of Florida. Also, the roadway number of I-95 in each county is different, and the milepost restarts from zero at each county, and therefore is different from the state milepost. To convert from the state milepost to the county-based linear reference system, a reference table as shown in Table 4-2 was created. Table 4-2 shows the I-95's roadway number and segment length in each county. The state milepost in this table shows that the total length of I-95 in the state of Florida which is 369.857 miles. By using this reference table, the sample detector locations in Table 4-2 were converted into associated roadway numbers and mileposts which are listed in Table 4-3.

Table 4-1 Sample Detector Location Definition in STEWARD

STATION_ID	STATION_DESC	STATION_MP
410011	I-95 NB North of Miami-Dade	17.40
410021	I-95 NB At Hallandale Beach Blvd	18.00
410031	I-95 NB North of Hallandale Bch Blvd	18.40
410041	I-95 NB At Pembroke Rd	18.80

Table 4-2 Reference Table for Converting State Mileposts to County Mileposts

ROADWAY ID	NAME	COUNTY	LENGTH (MI)	STATE MILEPOST (MI)
74160000	I-95	Nassau	12.226	369.857
72290000	I-95	Duval	10.513	359.344
72020000	I-95	Duval	10.593	348.751
72280000	I-95	Duval	16.793	331.958
78080000	I-95	St. Johns	34.855	297.103
73001000	I-95	Flagler	18.729	278.374
79002000	I-95	Volusia	45.804	232.570
70225000	I-95	Brevard	31.190	201.380
70220000	I-95	Brevard	41.503	159.877
88081000	I-95	Indian River	19.198	140.679
94001000	I-95	St. Lucie	27.259	113.420
89095000	I-95	Martin	24.835	88.585
93220000	I-95	Palm Beach	46.018	42.567
86070000	I-95	Broward	25.307	17.260
87270000	I-95	Miami-Dade	17.260	0.000

Source: (Courage and Lee, 2009)

Table 4-3 Sample Detector Location Definition in FHIS

STATION_ID	STATION_DESC	STATION_MP	ROADWAY	MILEPOST
410011	I-95 NB North of Miami-Dade	17.40	86070000	0.14
410021	I-95 NB At Hallandale Beach Blvd	18.00	86070000	0.74
410031	I-95 NB North of Hallandale Bch Blvd	18.40	86070000	1.14
410041	I-95 NB At Pembroke Rd	18.80	86070000	1.54

CHAPTER 5
SYSTEM INTERFACE AND FUNCTIONALITY

This chapter describes the user interface and the available functions of the system. The system was developed using ASP.NET 3.5 and C#.NET within the Microsoft Visual Studio 2008 environment. With the support of ArcGIS Server and SSRS 2008, the system helps the users perform data query, analysis, GIS operations, and reporting functions. In addition to the databases described in the previous chapter, the system also provides linkages to data external to the system, including Microsoft's Bing Maps, Google's Street View, and ESRI's ArcGIS Online.

5.1. Main System Screen

Figure 5-1 shows the main screen of the system. The screen forms the control center from which the users can query data and perform analysis with the help of the built-in tools and menu functions. It includes four major components: the main menus, the left panels, the shortcut toolbar, and the map.

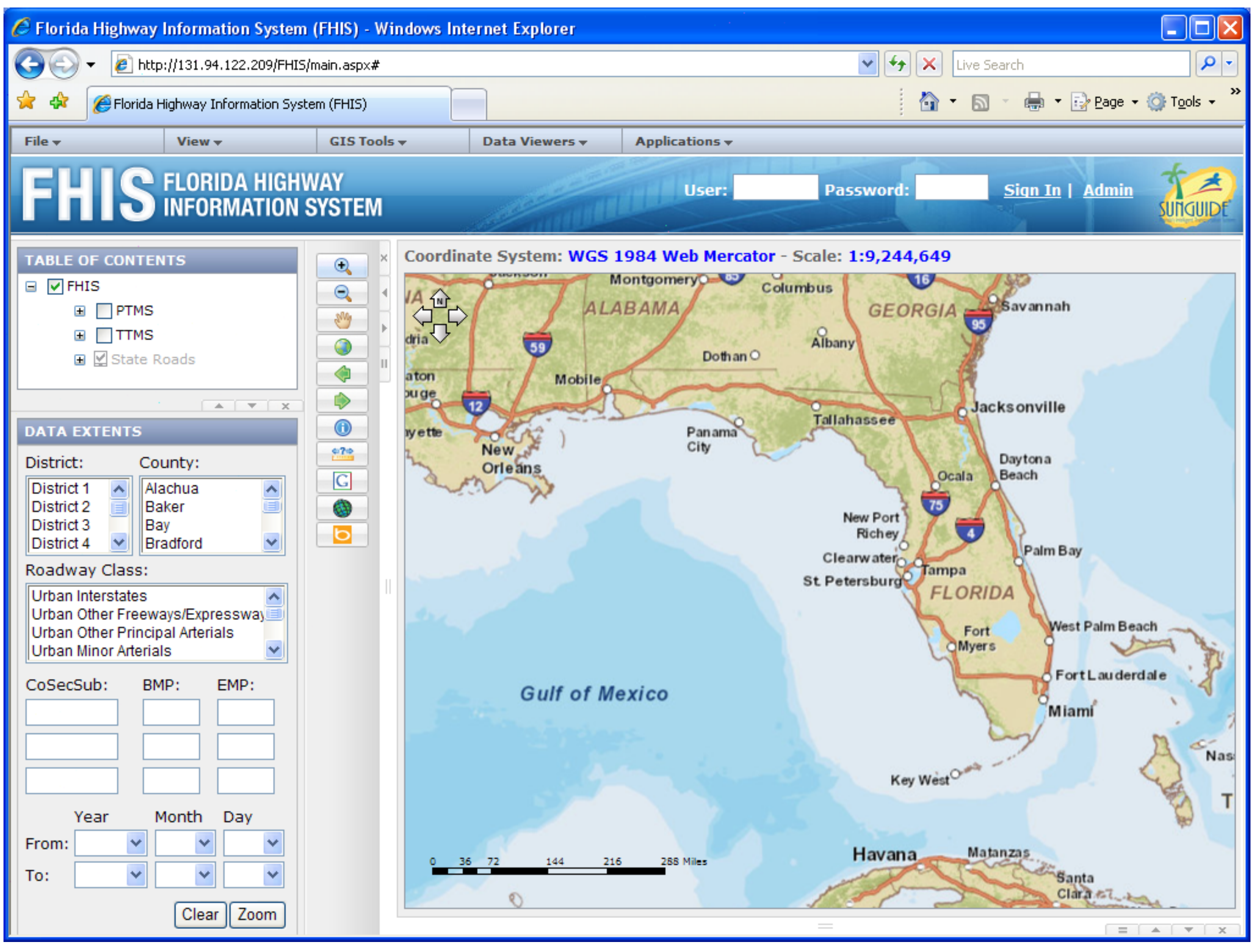


Figure 5-1 Main System Screen

5.1.1. Main Menus

At the top of the main application screen there are five main menus: **File**, **View**, **GIS Tools**, **Data Viewers**, and **Applications**. These menus allow the users to perform GIS operations, data analysis and report services, and evaluate ramp signal warrants. Functions included in each of these menus are introduced in Sections 5.2 through 5.7.

5.1.2. Left Panels

The main screen includes two left panels: the **Table of Contents** panel and the **Data Extents** panel. The **Table of Contents** panel is a GIS legend panel which lists all GIS layers (both visible and invisible). The checkbox beside the layer name controls layer's visibility.

The **Data Extents** panel allows the user to select specific districts, counties, roadway facilities, locations, and time range for data queries. The **District** list box allows the user to select one or more of the eight FDOT districts (including the Turnpike district) for data retrieval. To select multiple districts, the user needs to hold down the Control key while clicking on a list item. All the counties in the selected districts will be listed on the **County** list box. The user can narrow down the search to specific counties by clicking on one or more counties on the list. Using the same operations as described, the user can further limit the query to specific types of roadway facilities by clicking items on the **Roadway Class** list. When no items are selected in any of the lists, the query will assume that all list items are to be included. For example, if no districts are selected, all districts will be included.

The **Data Extents** panel also allows the user to select up three specific locations by entering the entering the standard FDOT linear reference location IDs for these locations. Each location is defined by its roadway numbered (**CoSecSub**), begin milepost (**BMP**), and end milepost (**EMP**) The Roadway ID entry is comprised of a two-digit county number, a three-digit section number, and a three-digit subsection number (e.g., 87270000).

Lastly, the **Data Extents** panel allows the user to specific a time range for the data to be included in the query output. The time range can go from a specific year, month and day to another. If the user simply wants to include, for example, data for 2005-2010, he/she would enter 2005 for the **From** year and 2010 for the **To** year and leave the month and day fields empty. Entering the **From** and **To** months would further narrow down the search to the time range based on month, e.g., from June 2005 to June 2010. It is noted, however, that any entry for month must also accompany the corresponding year, and any entry for day must also accompany the corresponding month and year. Leaving all the fields empty will assume that no time restrictions will be applied and the query will include all available data in the database.

At the bottom of the **Data Extents** panel, the **Clear** and **Zoom** buttons are provided. The **Clear** button will clear all selections and inputs in the **Data Extents** panel. The **Zoom** button allows the users to zoom into the current map view to a more detailed level to cover the specific locations defined in the **CoSecSub**, **BMP**, and **EMP** textboxes. As shown in Figure 5-2, the map is zoomed into the roadway number 87270000 (I-95 in Miami-Dade County) highlighted with the aqua color.

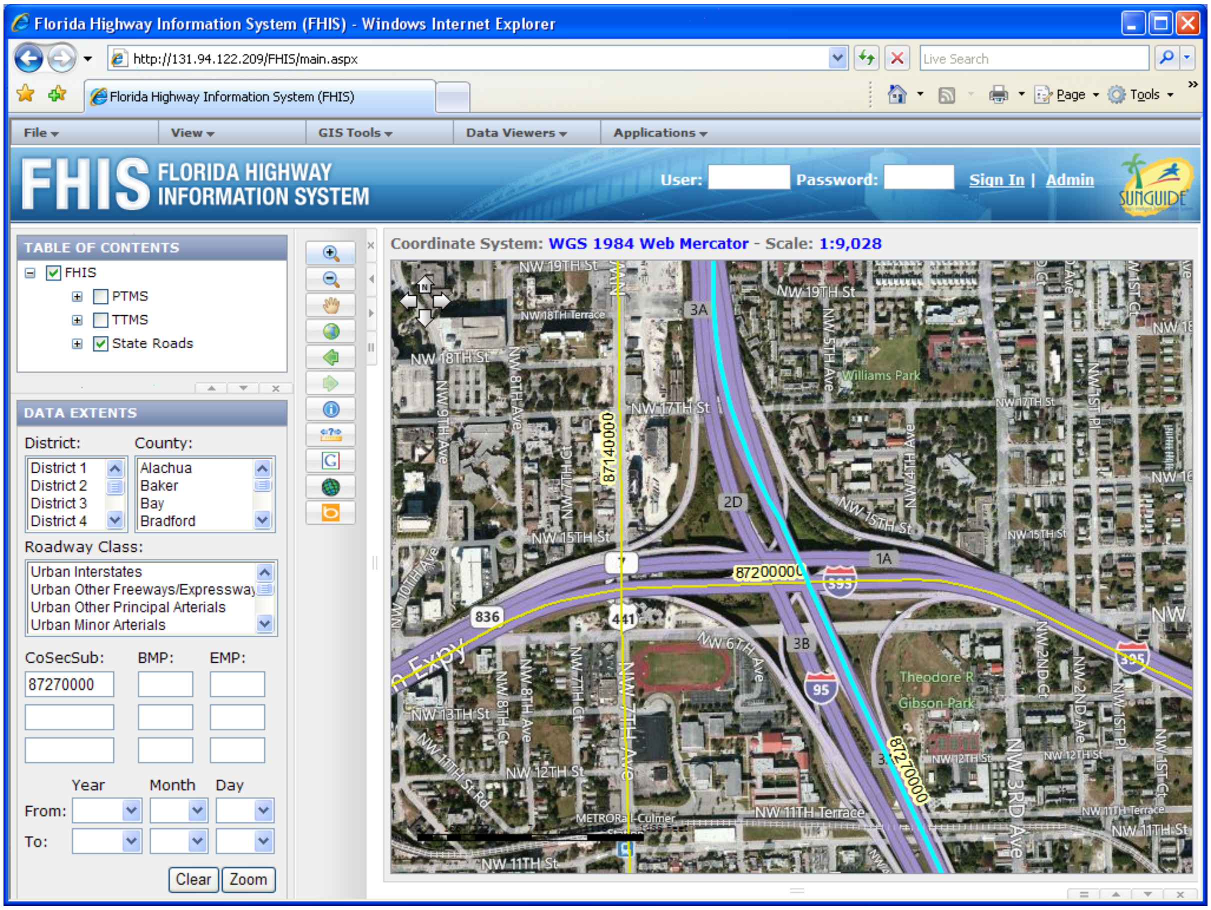


Figure 5-2 GIS Map with Bing Maps Aerial Photo Background

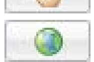
5.1.3. Shortcut Toolbar

A vertical tool bar with the shortcut options for basic GIS operations is placed to the right of the **Table of Contents** and **Data Extents** panels. The following basic GIS operation modes are used to interact with the map and its elements.

 Zoom In: Zoom in to a geographic window by clicking a point or dragging a box

 Zoom Out: Zoom out from a geographic window by clicking a point or dragging a box

 Pan: Pan the map

 Full Extent: Zoom to the full extent of the map

 Previous Extent: Zoom to the previous extent of the map

 Next Extent: Zoom to the next extent of the map (if available)

 Identify: Identify the geographic features (on the visible layers) on which the user clicks

Measure:	Displays the X, Y coordinates of a point, measures the distance between two points, and displays the perimeter and area of a polygon.
Google Street View:	Shows the Google Street View of by clicking on a roadway location.
Toggle ESRI map:	Toggles the ESRI World Street Map on or off
Toggle Bing maps:	Toggles the Microsoft Bing Maps on or off

An example of the **Identify** function with the information window is shown in Figure 5-3. In the information window, the attribute values are listed for the spatially selected state road. The **Add to Result** link at the bottom of the information window will add the selected state road to the **Results** panel (as shown in Figure 5-4) which is displayed below the map view area. In the **Results** panel, users have the capabilities to perform basic actions and export selected features into a CSV (comma separated value) file or a Shapefile.

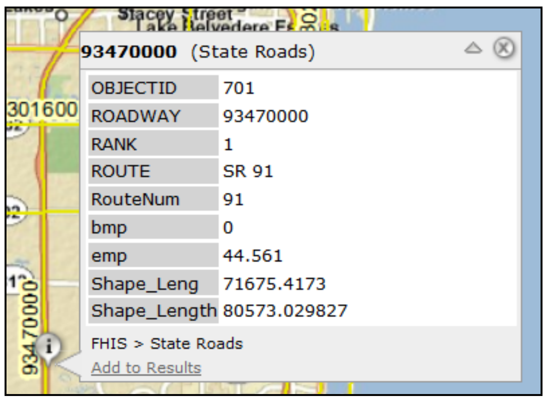


Figure 5-3 Information Dialog Box in the Identify Mode

The **Google Street View** operation mode allows the users to see the street images provided by Google Maps. After the **Google Street View** button is clicked (toggled), the user can click on any location on the map, such as an intersection, a landmark, or a street, and the system will automatically pop up a **Google Street View** window for the location. Figure 5-5 shows an example.

Using the Bing Maps extension for ArcGIS Server 9.3.1, Microsoft Bing Maps is integrated into FHIS for quick display of a basemap as background. Microsoft Bing Maps, formally Microsoft Virtual Earth, are tiled road and aerial maps developed and administered by Microsoft. Inside ArcGIS Server 9.3.1, there are three types of Bing Maps: Bing Maps Road, Bing Maps Aerial, and Bing Maps Hybrid. Bing Maps Hybrid includes imagery overlaid with roads and labels; this map service is selected for the current system.

ArcGIS Online, an ESRI product, hosts basemaps that can be used seamlessly in ArcGIS map service applications. From a rich set of basemaps, the World Street Map option is selected as the default basemap for FHIS. This map service presents highway-level data for the world and street-level data for North America, and more. The map shown in Figure 5-4 came from the World Street Map.

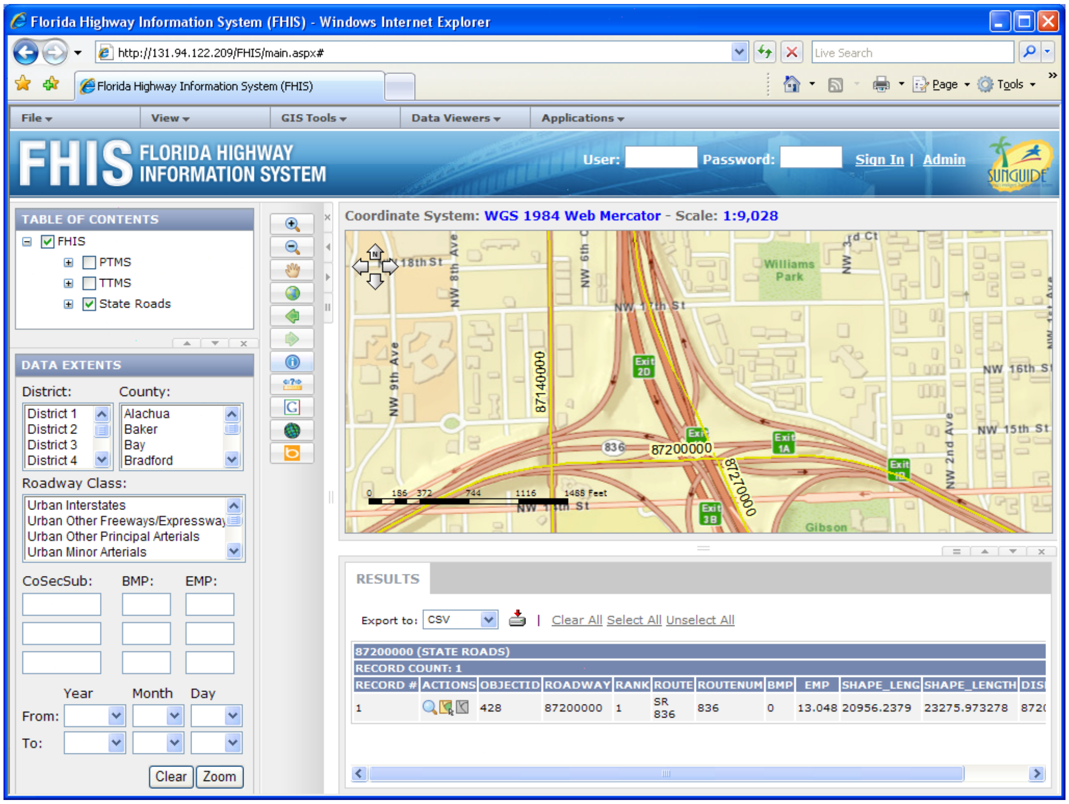


Figure 5-4 Results Panel with Added Roadway Feature

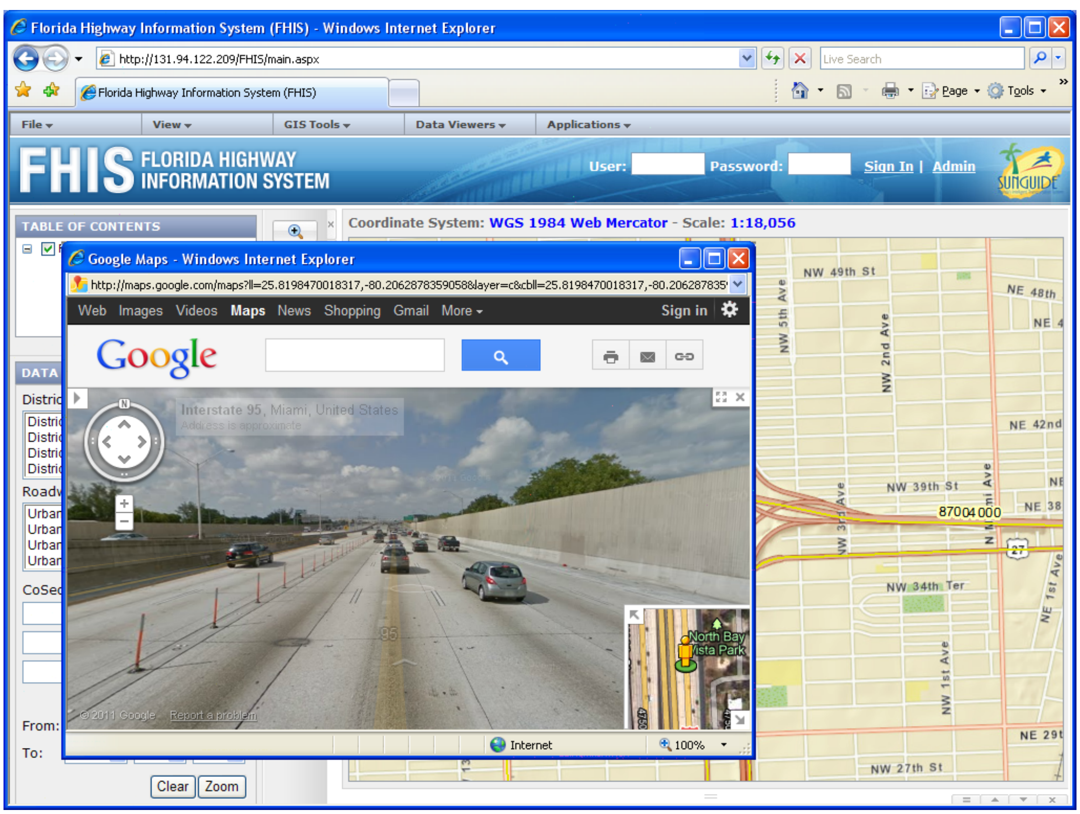


Figure 5-5 Google Street View Popup Window

5.2. File Menu

This main menu has two submenus to print and export the viewed map.

5.2.1. Print

The **Print** submenu gives users the option to add a title to the map. In the same window, the layout of the map could also be defined. The map could be printed either with a disclaimer or with a legend. In addition to the map template, map width and map resolution could be set by the users. Figure 5-6 shows the **Print** dialog box. Figure 5-7 shows a sample map in the **Print Review** mode.

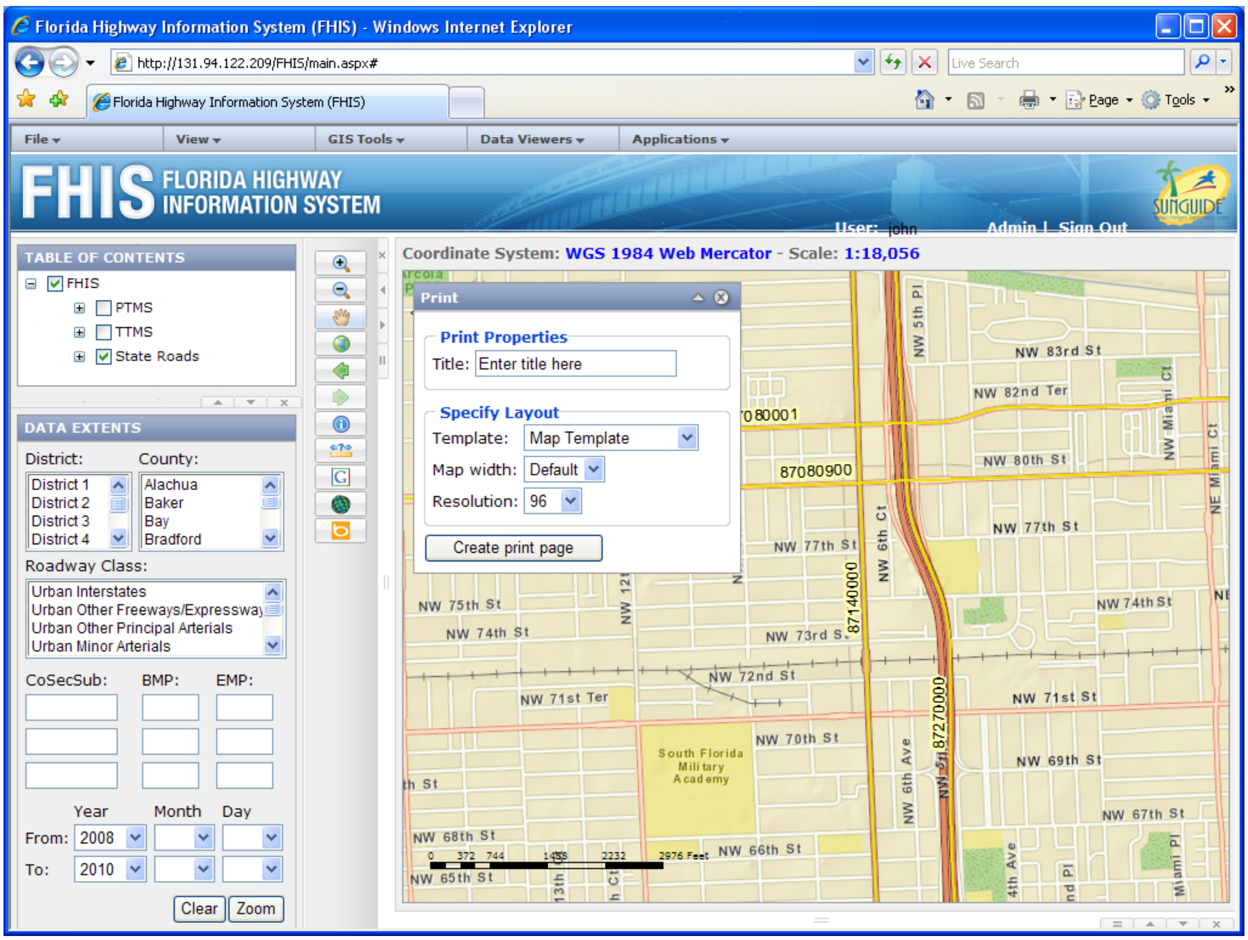


Figure 5-6 Print Dialog Box

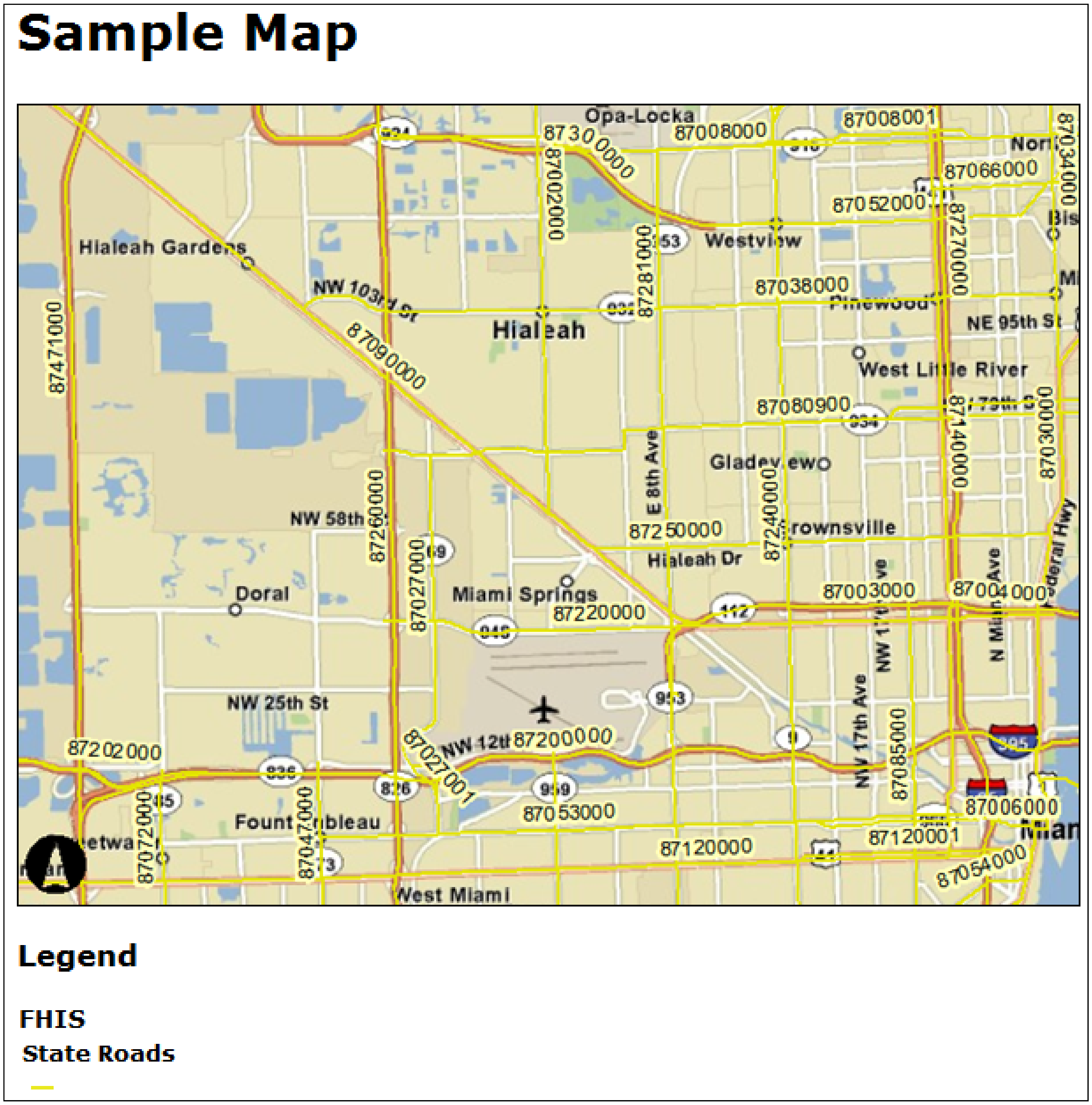


Figure 5-7 Sample Map with Legend in Print Preview Mode

5.2.2. Export

The **Export** submenu gives the user an option to export the map to an image file for download. The map could be exported in the following formats: PNG24, BMP, EMF, GIF, JPG, JPG, PNG, TIFF. In addition to the output format, map width could also be defined by the user. Figure 5-8 shows the Export dialog box.

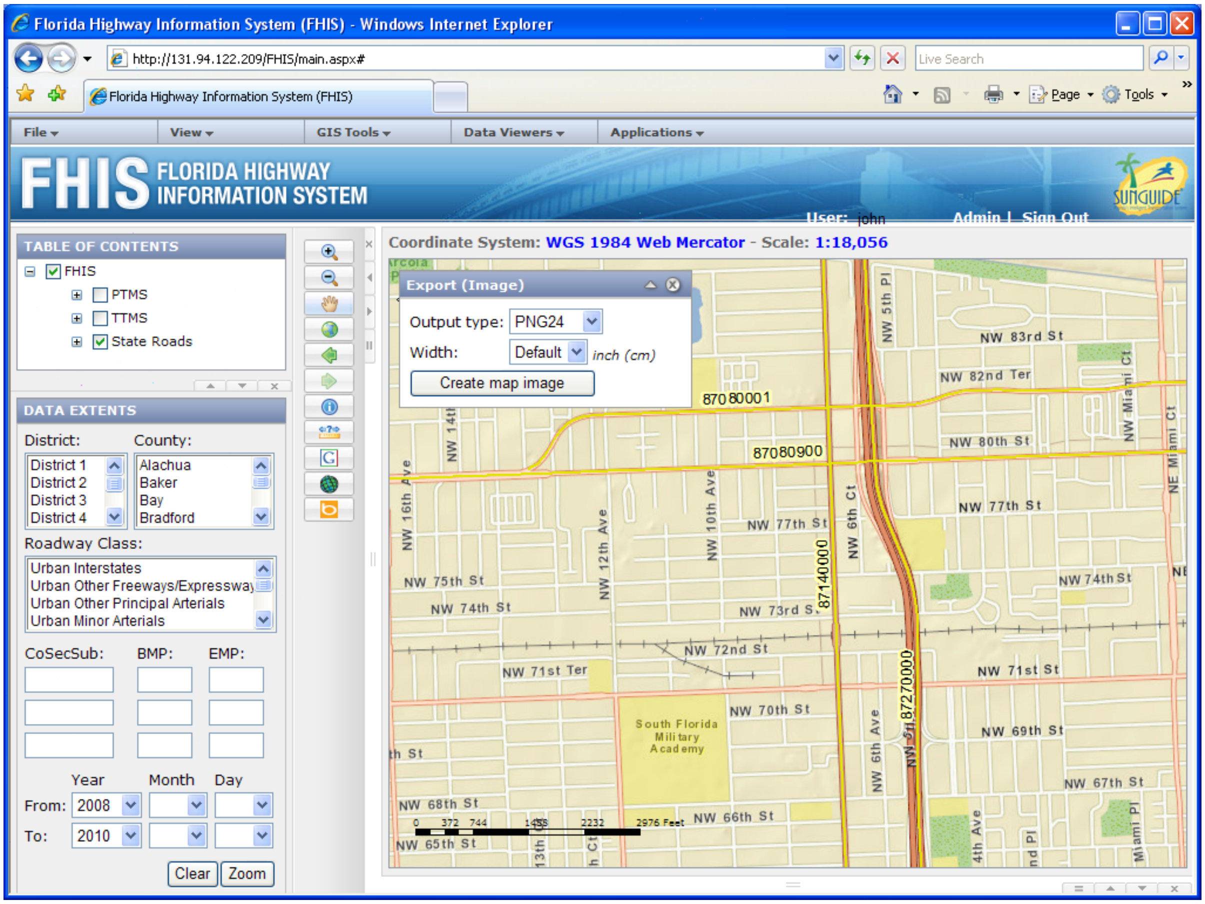


Figure 5-8 Export Dialog Box

5.3. View Menu

This menu enables the user to restore the legend panel, the data extents panel, and the results panel, if they are hidden (after clicking the "x" close button located at an edge of a panel). These submenus are useful when the user wants to switch the view from full screen mode to the default view. Figure 5-9 shows:

- The **Show Left Panel** menu item allows the users to select it to bring back the **Table of Contents** and the **Data Extents** panels that are closed.

- The **Show Data Extents Panel** menu item allows the user to select to bring back the **Data Extents** panel that is closed.

- The **Show Results Panel** menu item allows the users to open a panel (see Figure 5-4) below the map to view the selection results in tabular format. It is noted that the **Results Panel** displays results only when a selection has been made.

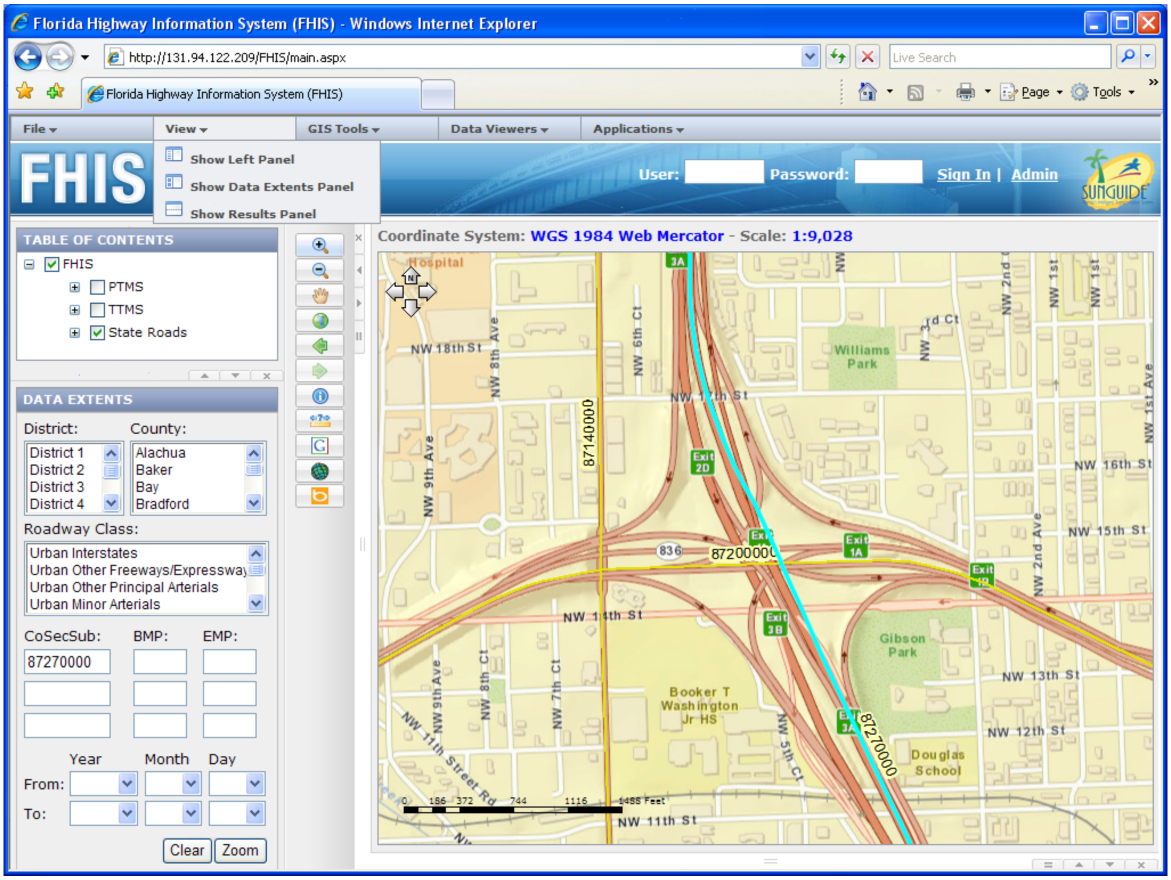


Figure 5-9 Main Application Screen with Submenus of the View Menu

<u>5.4. GIS Tools Menu</u>

This main menu provides four functions to draw different graphical symbols, labels, and shapes on the map for better illustrations. Figure 5-10 shows the screenshot of the main application screen with the GIS Tools menu items. The specific functions are described below:

- The **Draw Graphic** tool gives the user an option to mark locations of interest using any one of the available graphics. The user can also upload a new graphic using the **Upload New Graphic Window** (as shown in Figure 5-11). Based on the user requirements, graphics can be placed or deleted. For increased convenience, an option to delete all graphics at once is also provided.

- The **Draw Label** tool provides the user with an option to label locations of interest. The font, size, color, and label text can be inserted by the user. Based on the user requirements, labels can be placed or deleted. For increased convenience, an option to delete all labels at once is also provided.

- The **Draw Shape** tool provides the user with an option to draw several shapes including point, line, polygon, and a rectangle. The point style (i.e., type, width, and color) can also be selected. Further, the shapes can also be deleted.

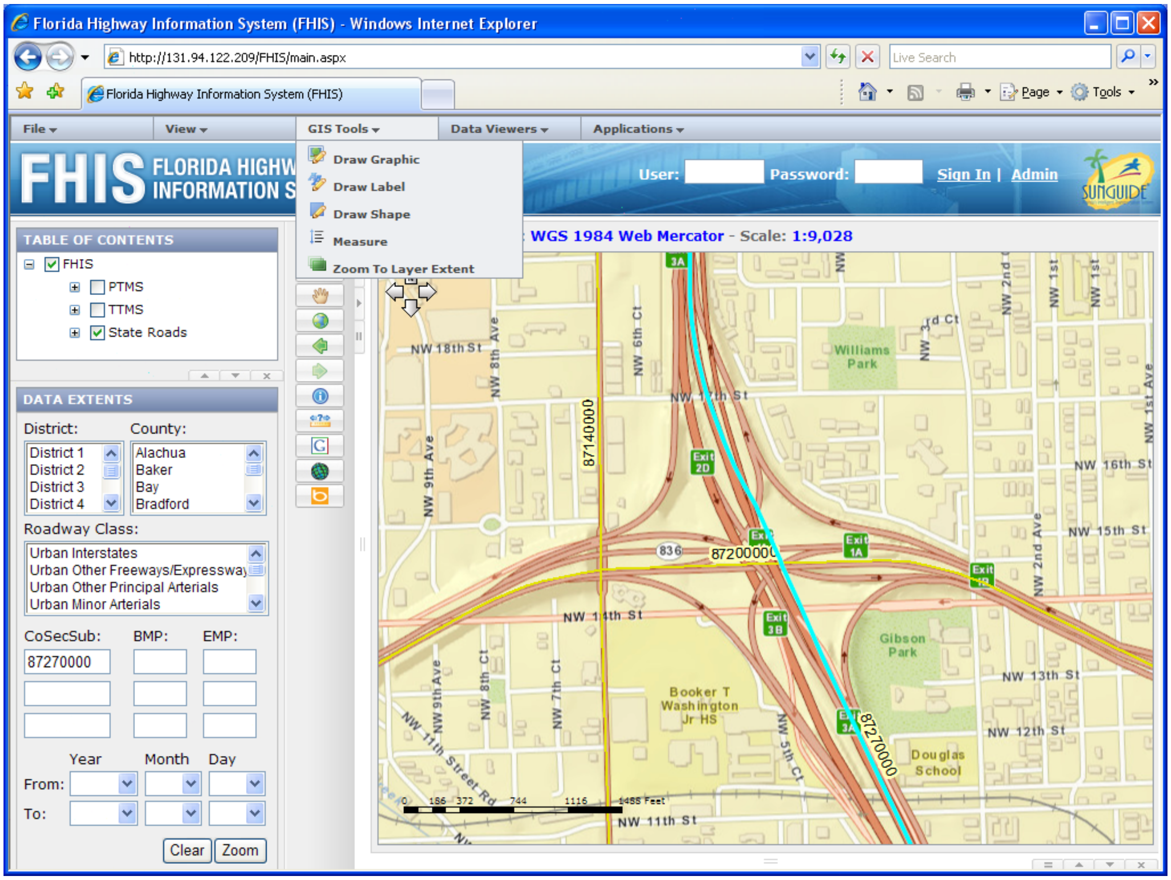


Figure 5-10 Main Application Screen with Submenus of the GIS Tools Menu

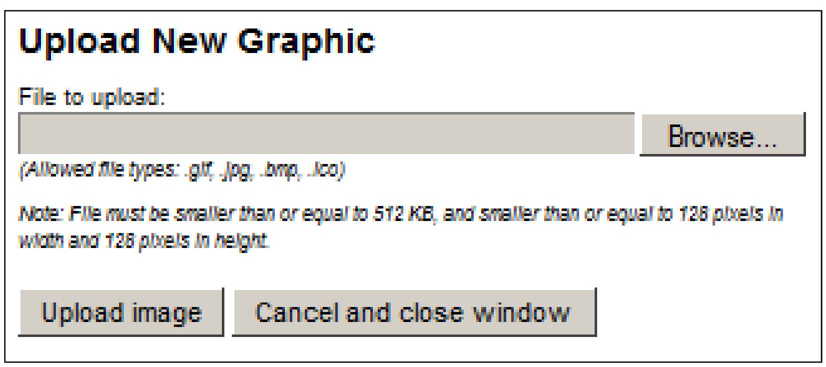


Figure 5-11 "Upload New Graphic" Window

- The **Measure** tool allows the user to get the X, Y coordinates of a point, measure the distance between two points, or obtain the perimeter and area of a polygon.

- The **Zoom to Layer Extent** tool zooms the map to the extent of the selected layer.

The dialog boxes of the tools described above are shown in Figure 5-12.

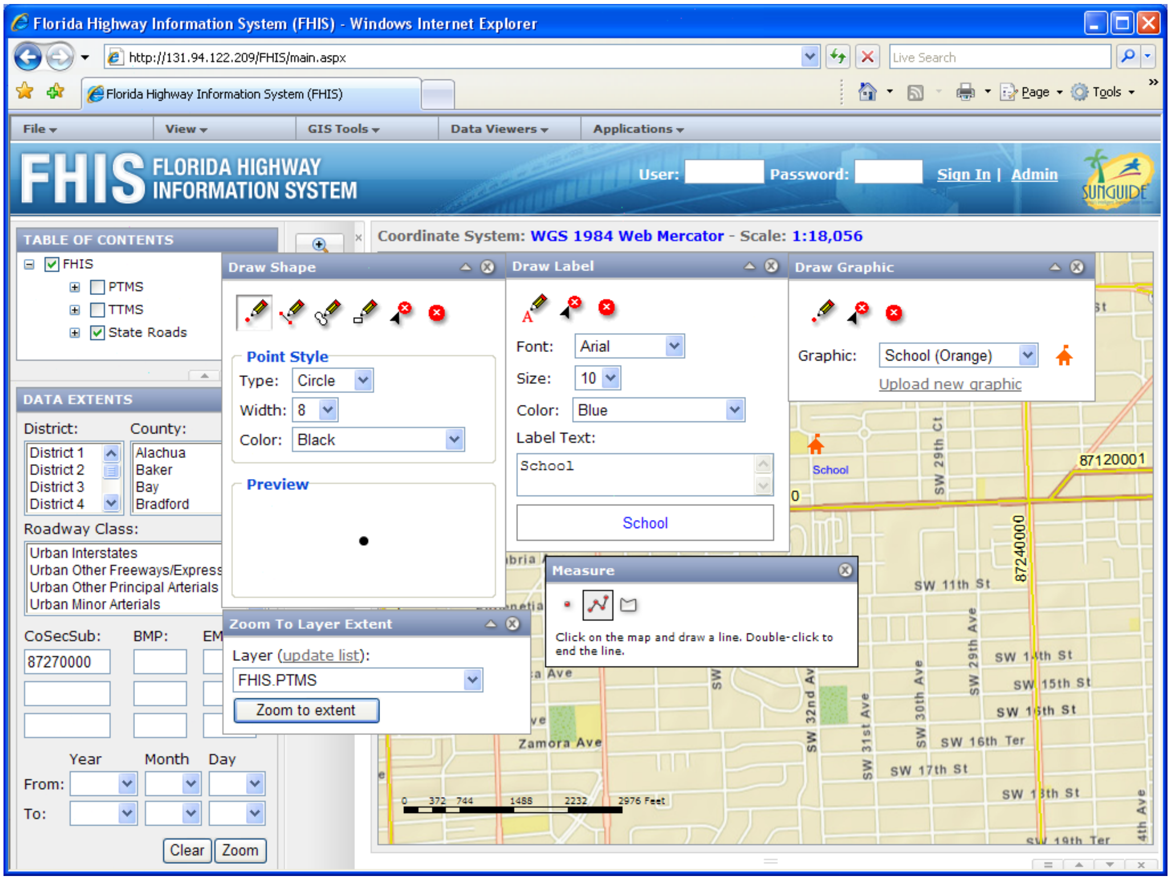


Figure 5-12 A Sample Map with School Graphic Inserted and Labeled

5.5. Data Viewers Menu

As shown in Figure 5-13, a total of five menu items (RCI data, Crash records, Incident records, Detector data, and Traffic counts) are listed under the **Data Viewers** menu. Clicking each menu item will pop up a new page to display the raw data extracted from the associated data table for the selected study locations. The popup pages contain more detailed analysis and report services.

As indicated previously, the system architecture takes advantage of SSRS features and builds an analysis and reporting service platform. Data in all the five main data tables can be queried and analyzed inside this platform, and the query and analysis results are displayed in report style in a page.

5.5.1. Crash Data Viewer

After defining query criteria, and then clicking the **Crash Data Viewer** menu item, the system will pop up a crash data analysis report page inside which all queried crash records are displayed and related analysis could be performed. Figure 5-14 shows a report listing the original extracted crash records. In this data viewer page, the user can obtain descriptive statistics and detailed column wise summaries in the form of bar charts. Using the **Format** dropdown list, all data and charts can be exported to XML, CSV, Excel, PDF, TIFF, and Word data file for further use outside the system.

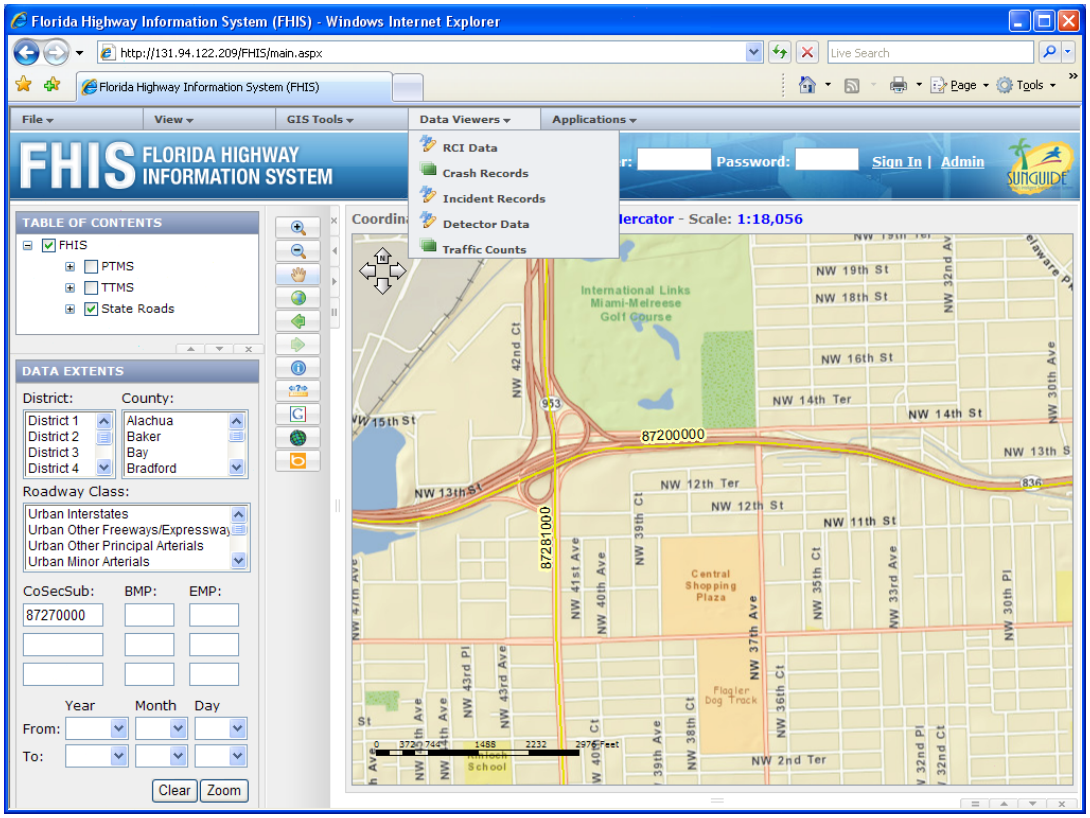
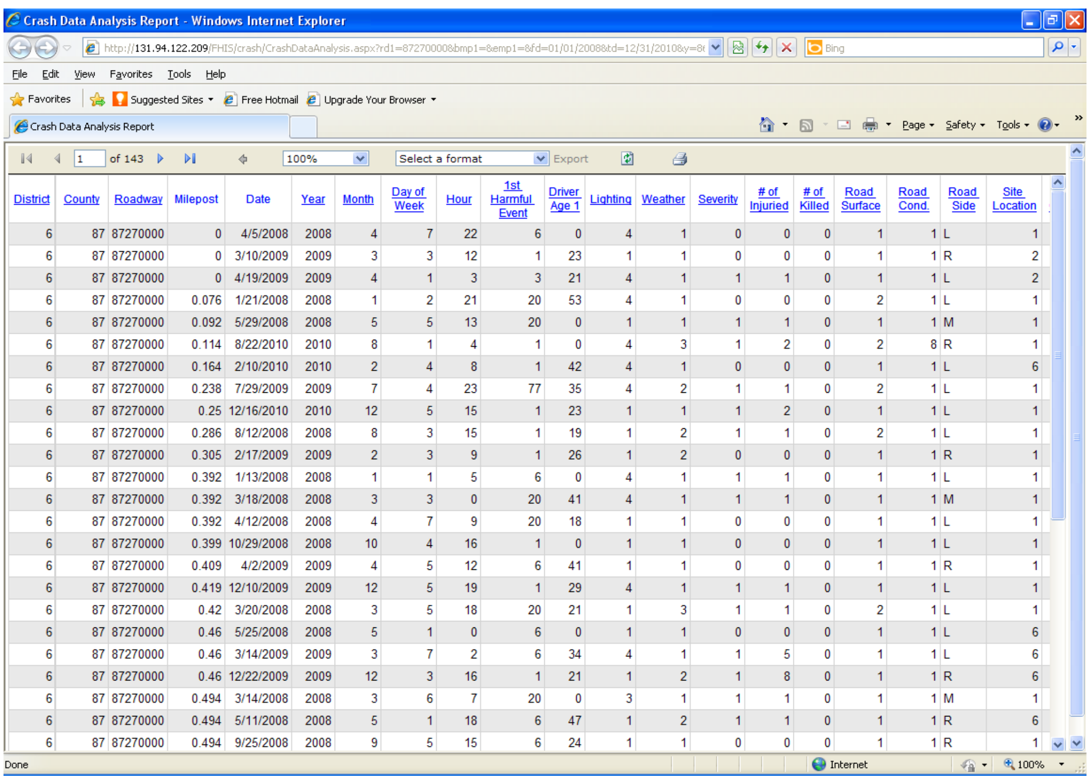


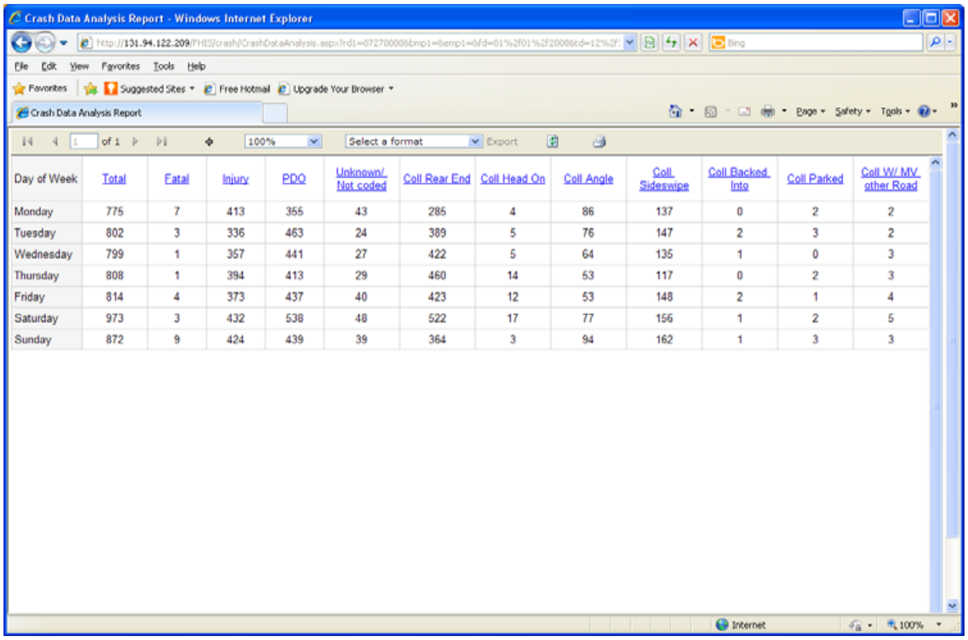
Figure 5-13 Main Application Screen with Submenus of the Data Viewers Menu



District	County	Roadway	Milepost	Date	Year	Month	Day of Week	Hour	1st Harmful Event	Driver Age 1	Lighting	Weather	Severity	# of Injuried	# of Killed	Road Surface	Road Cond.	Road Side	Site Location
6	87	87270000	0	4/5/2008	2008	4	7	22	6	0	4	1	0	0	0	1	1	L	1
6	87	87270000	0	3/10/2009	2009	3	3	12	1	23	1	1	0	0	0	1	1	R	2
6	87	87270000	0	4/19/2009	2009	4	1	3	3	21	4	1	1	1	0	1	1	L	2
6	87	87270000	0.076	1/21/2008	2008	1	2	21	20	53	4	1	0	0	0	2	1	L	1
6	87	87270000	0.092	5/29/2008	2008	5	5	13	20	0	1	1	1	1	0	1	1	M	1
6	87	87270000	0.114	8/22/2010	2010	8	1	4	1	0	4	3	1	2	0	2	8	R	1
6	87	87270000	0.164	2/10/2010	2010	2	4	8	1	42	4	1	0	0	0	1	1	L	6
6	87	87270000	0.238	7/29/2009	2009	7	4	23	77	35	4	2	1	1	0	2	1	L	1
6	87	87270000	0.25	12/16/2010	2010	12	5	15	1	23	1	1	1	2	0	1	1	L	1
6	87	87270000	0.286	8/12/2008	2008	8	3	15	1	19	1	2	1	1	0	2	1	L	1
6	87	87270000	0.305	2/17/2009	2009	2	3	9	1	26	1	2	0	0	0	1	1	R	1
6	87	87270000	0.392	1/13/2008	2008	1	1	5	6	0	4	1	1	1	0	1	1	L	1
6	87	87270000	0.392	3/18/2008	2008	3	3	0	20	41	4	1	1	1	0	1	1	M	1
6	87	87270000	0.392	4/12/2008	2008	4	7	9	20	18	1	1	0	0	0	1	1	L	1
6	87	87270000	0.399	10/29/2008	2008	10	4	16	1	0	1	1	0	0	0	1	1	L	1
6	87	87270000	0.409	4/2/2009	2009	4	5	12	6	41	1	1	0	0	0	1	1	R	1
6	87	87270000	0.419	12/10/2009	2009	12	5	19	1	29	4	1	1	1	0	1	1	L	1
6	87	87270000	0.42	3/20/2008	2008	3	5	18	20	21	1	3	1	1	0	2	1	L	1
6	87	87270000	0.46	5/25/2008	2008	5	1	0	6	0	1	1	0	0	0	1	1	L	6
6	87	87270000	0.46	3/14/2009	2009	3	7	2	6	34	4	1	1	5	0	1	1	L	6
6	87	87270000	0.46	12/22/2009	2009	12	3	16	1	21	1	2	1	8	0	1	1	R	6
6	87	87270000	0.494	3/14/2008	2008	3	6	7	20	0	3	1	1	1	0	1	1	M	1
6	87	87270000	0.494	5/11/2008	2008	5	1	18	6	47	1	2	1	1	0	1	1	R	6
6	87	87270000	0.494	9/25/2008	2008	9	5	15	6	24	1	1	0	0	0	1	1	R	1

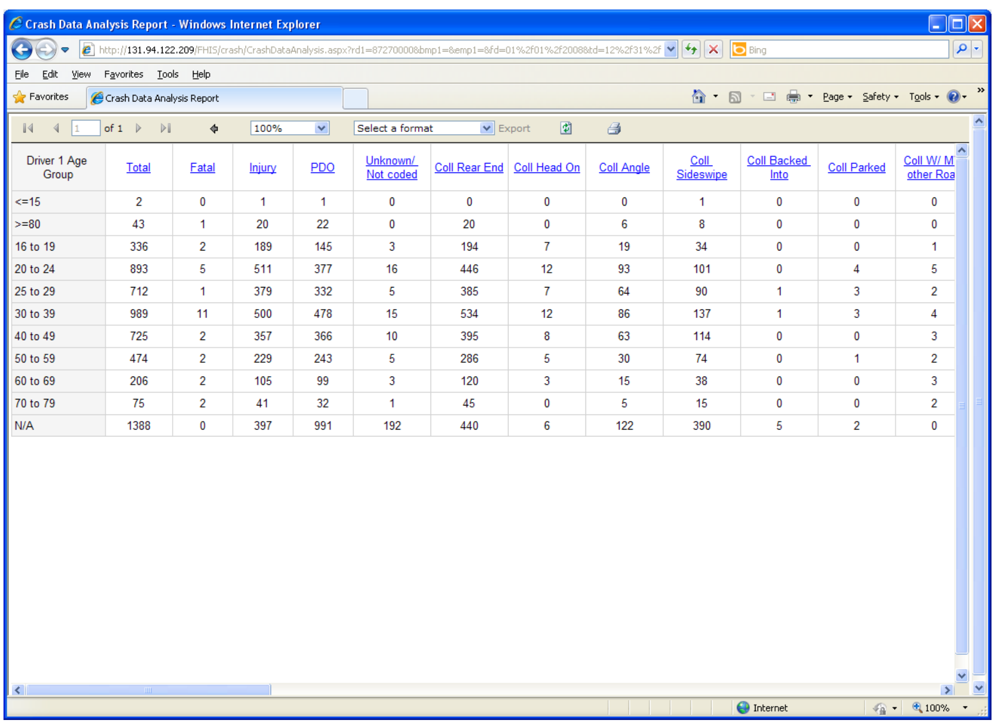
Figure 5-14 Extracted Crash Records

Figures 5-15 and 5-16 show the crash summary information grouped by the day of week and driver's age. The column headers for this summary report have two groups: crash severity type and harmful event type. Clicking on any severity or harmful event type will produce a bar chart report. Figures 5-17 and 5-18 show the bar charts for total crash numbers grouped by the day of week, and the number of rear-end collisions grouped by the day of week.



Day of Week	Total	Fatal	Injury	PDO	Unknown/ Not coded	Coll Rear End	Coll Head On	Coll Angle	Coll Sideswipe	Coll Backed Into	Coll Parked	Coll W/ MV other Road
Monday	775	7	413	355	43	285	4	86	137	0	2	2
Tuesday	802	3	336	463	24	389	5	76	147	2	3	2
Wednesday	799	1	357	441	27	422	5	64	135	1	0	3
Thursday	808	1	394	413	29	460	14	53	117	0	2	3
Friday	814	4	373	437	40	423	12	53	148	2	1	4
Saturday	973	3	432	538	48	522	17	77	156	1	2	5
Sunday	872	9	424	439	39	364	3	94	162	1	3	3

Figure 5-15 Crash Summary Report Grouped by Day of Week



Driver 1 Age Group	Total	Fatal	Injury	PDO	Unknown/ Not coded	Coll Rear End	Coll Head On	Coll Angle	Coll Sideswipe	Coll Backed Into	Coll Parked	Coll W/ M other Roa
<=15	2	0	1	1	0	0	0	0	1	0	0	0
>=80	43	1	20	22	0	20	0	6	8	0	0	0
16 to 19	336	2	189	145	3	194	7	19	34	0	0	1
20 to 24	893	5	511	377	16	446	12	93	101	0	4	5
25 to 29	712	1	379	332	5	385	7	64	90	1	3	2
30 to 39	989	11	500	478	15	534	12	86	137	1	3	4
40 to 49	725	2	357	366	10	395	8	63	114	0	0	3
50 to 59	474	2	229	243	5	286	5	30	74	0	1	2
60 to 69	206	2	105	99	3	120	3	15	38	0	0	3
70 to 79	75	2	41	32	1	45	0	5	15	0	0	2
N/A	1388	0	397	991	192	440	6	122	390	5	2	0

Figure 5-16 Crash Summary Report Grouped by Driver's Age

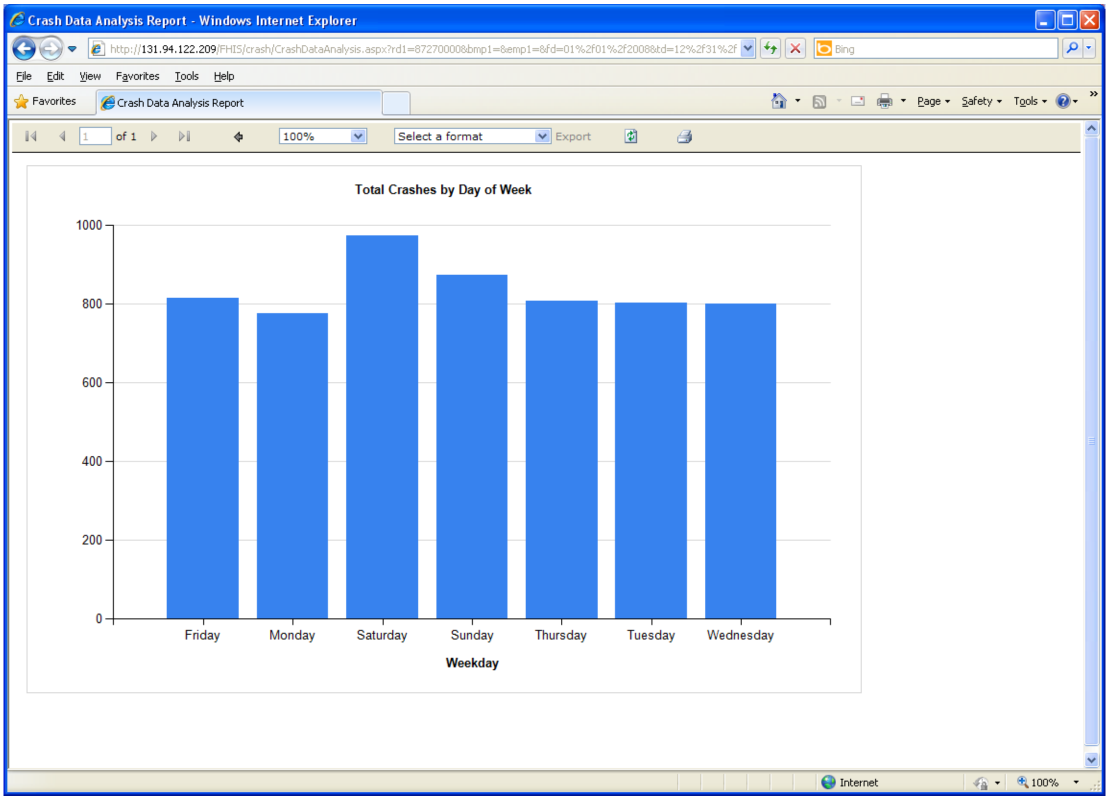


Figure 5-17 Bar Chart for Total Crash Numbers by Day of Week

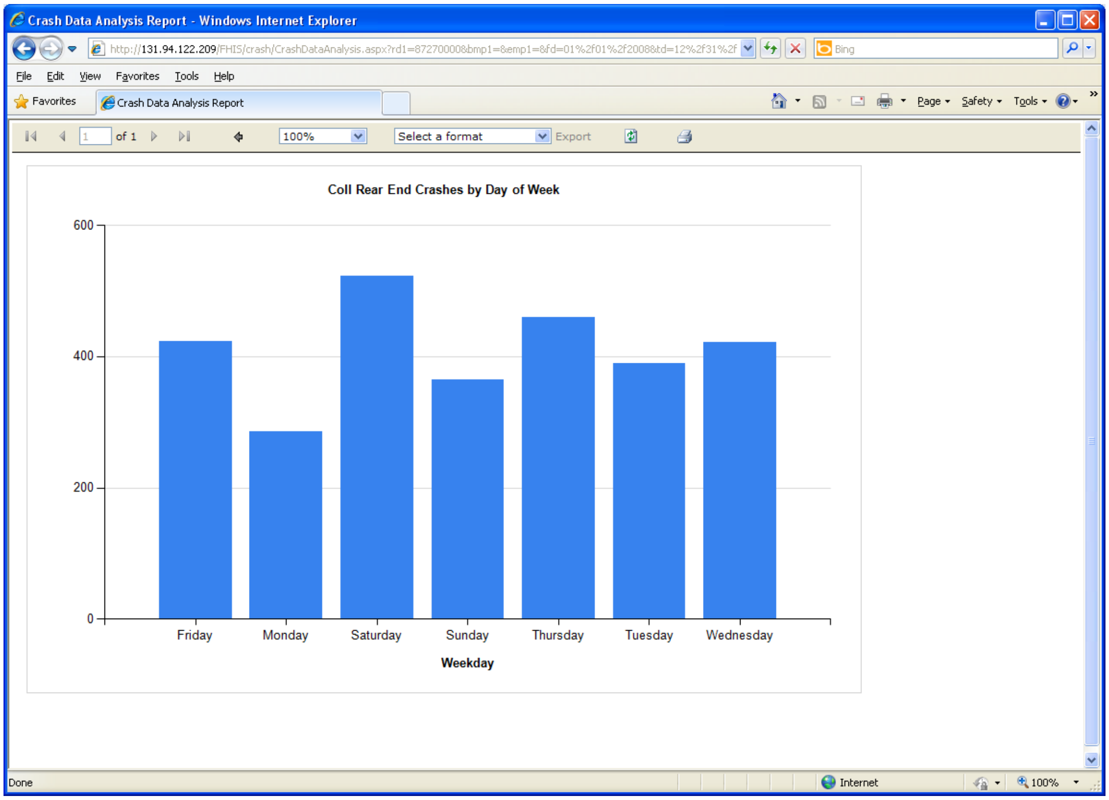
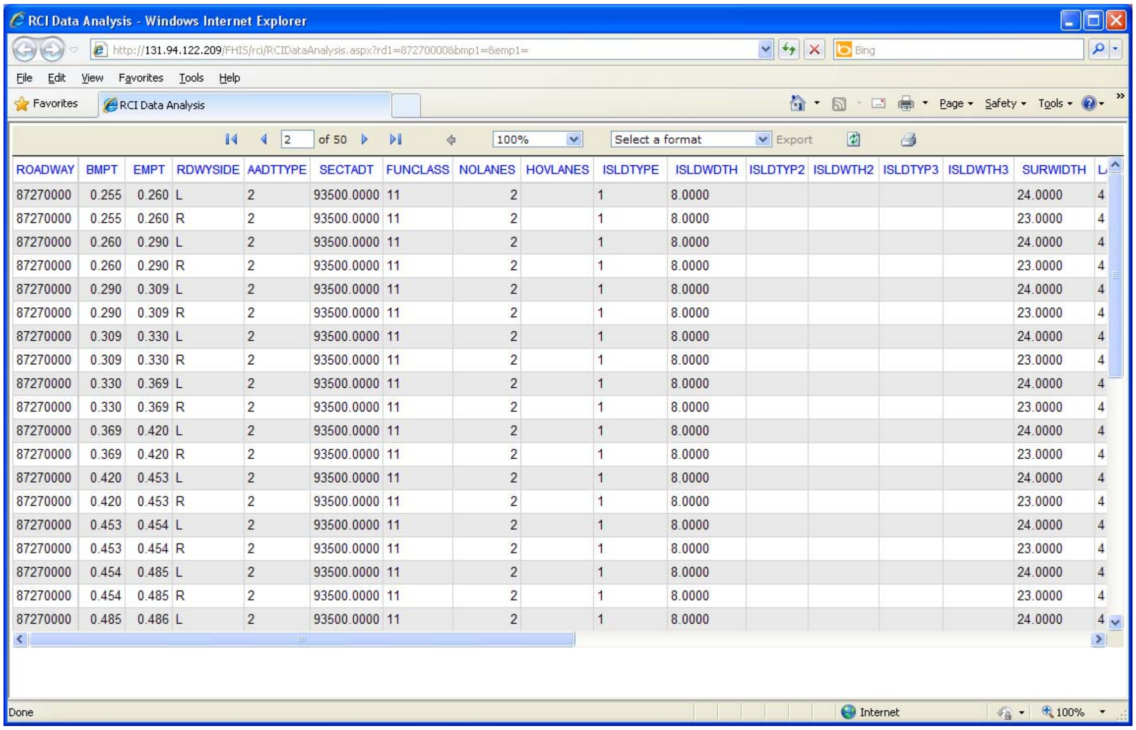


Figure 5-18 Bar Chart for Rear-End Collisions by Day of Week

5.5.2. RCI Data Viewer

The current **RCI Data** viewer page only lists all extracted RCI raw data based on the criteria selected by the user. Figure 5-19 shows a report that lists the original extracted RCI records sorted by the roadway number, begin milepost, end milepost, and roadway characteristics. These data can be exported to XML, CSV, Excel, PDF, TIFF, and Word formats for further analysis outside the system.



ROADWAY	BMPT	EMPT	RDWYSIDE	AADTTYPE	SECTADT	FUNCLASS	NOLANES	HOVLANES	ISLDTYPE	ISLDWDTH	ISLDTYP2	ISLDWTH2	ISLDTYP3	ISLDWTH3	SURWIDTH	L
87270000	0.255	0.260	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.255	0.260	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.260	0.290	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.260	0.290	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.290	0.309	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.290	0.309	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.309	0.330	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.309	0.330	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.330	0.369	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.330	0.369	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.369	0.420	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.369	0.420	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.420	0.453	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.420	0.453	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.453	0.454	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.453	0.454	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.454	0.485	L	2	93500.0000	11	2		1	8.0000					24.0000	4
87270000	0.454	0.485	R	2	93500.0000	11	2		1	8.0000					23.0000	4
87270000	0.485	0.486	L	2	93500.0000	11	2		1	8.0000					24.0000	4

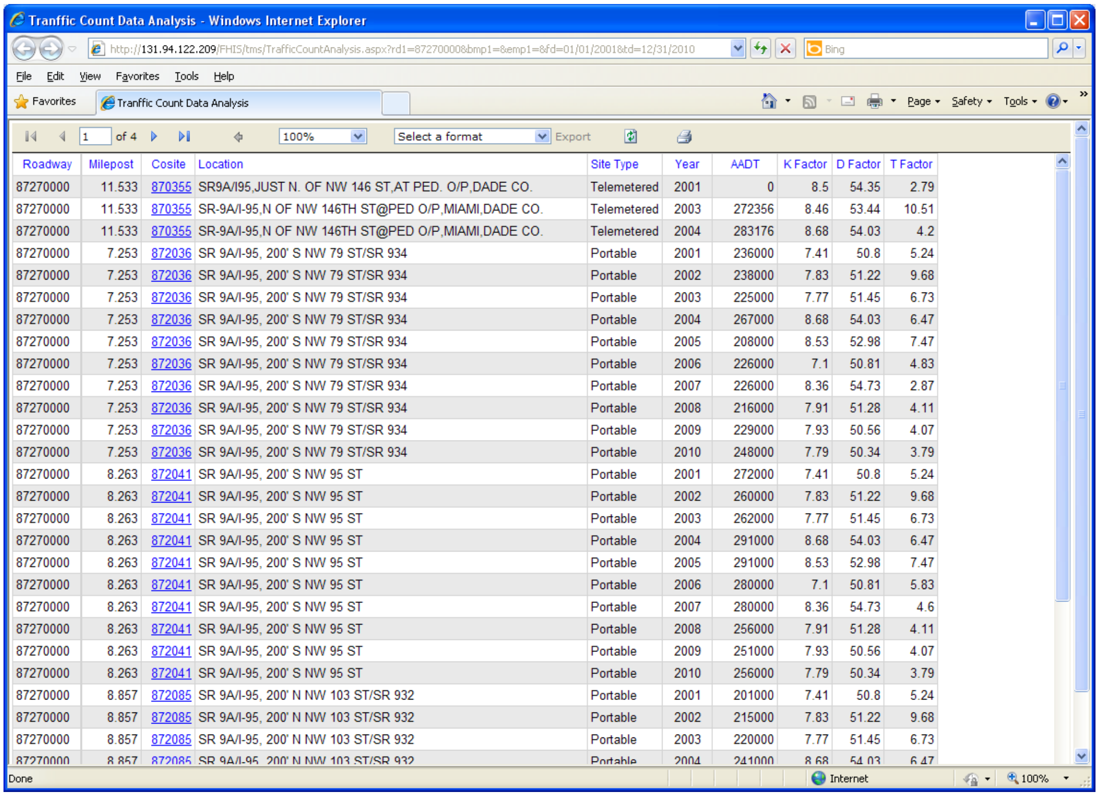
Figure 5-19 Queried RCI Data

5.5.3. Traffic Counts Viewer

The **Traffic Counts** data include AADT, T factor, K factor, and D factor information for both TTMS (Telemetry Traffic Monitoring Site) and PTMS (Portable Traffic Monitoring Site) sites. Figure 5-20 shows a page that lists the traffic counts for selected locations and years. In this page, users can click on a site number, underlined in blue color, and the site's traffic count information for selected years is displayed. Figures 5-21 and 5-22 show the line charts for the AADT, T factor, K factor, and D factor information for the site number 872036 for the years 2001 through 2010.

5.5.4. Incident Data Viewer

Supplementing several other data viewer pages, the **Incident Data** viewer page shows the original incident raw data (as shown in Figure 5-23) based on the locations and time period selected by users. With the built-in export function, these raw data can be exported for further analysis. The data analysis and reporting services are not available for the current system.



Roadway	Milepost	Cosite	Location	Site Type	Year	AADT	K Factor	D Factor	T Factor
87270000	11.533	870355	SR9A/I95,JUST N. OF NW 146 ST,AT PED. O/P,DADE CO.	Telemetered	2001	0	8.5	54.35	2.79
87270000	11.533	870355	SR-9A/I-95,N OF NW 146TH ST@PED O/P,MIAMI,DADE CO.	Telemetered	2003	272356	8.46	53.44	10.51
87270000	11.533	870355	SR-9A/I-95,N OF NW 146TH ST@PED O/P,MIAMI,DADE CO.	Telemetered	2004	283176	8.68	54.03	4.2
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2001	236000	7.41	50.8	5.24
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2002	238000	7.83	51.22	9.68
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2003	225000	7.77	51.45	6.73
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2004	267000	8.68	54.03	6.47
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2005	208000	8.53	52.98	7.47
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2006	226000	7.1	50.81	4.83
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2007	226000	8.36	54.73	2.87
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2008	216000	7.91	51.28	4.11
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2009	229000	7.93	50.56	4.07
87270000	7.253	872036	SR 9A/I-95, 200' S NW 79 ST/SR 934	Portable	2010	248000	7.79	50.34	3.79
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2001	272000	7.41	50.8	5.24
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2002	260000	7.83	51.22	9.68
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2003	262000	7.77	51.45	6.73
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2004	291000	8.68	54.03	6.47
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2005	291000	8.53	52.98	7.47
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2006	280000	7.1	50.81	5.83
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2007	280000	8.36	54.73	4.6
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2008	256000	7.91	51.28	4.11
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2009	251000	7.93	50.56	4.07
87270000	8.263	872041	SR 9A/I-95, 200' S NW 95 ST	Portable	2010	256000	7.79	50.34	3.79
87270000	8.857	872085	SR 9A/I-95, 200' N NW 103 ST/SR 932	Portable	2001	201000	7.41	50.8	5.24
87270000	8.857	872085	SR 9A/I-95, 200' N NW 103 ST/SR 932	Portable	2002	215000	7.83	51.22	9.68
87270000	8.857	872085	SR 9A/I-95, 200' N NW 103 ST/SR 932	Portable	2003	220000	7.77	51.45	6.73
87270000	8.857	872085	SR 9A/I-95, 200' N NW 103 ST/SR 932	Portable	2004	241000	8.68	54.03	6.47

Figure 5-20 Traffic Count Data for a Selected Roadway

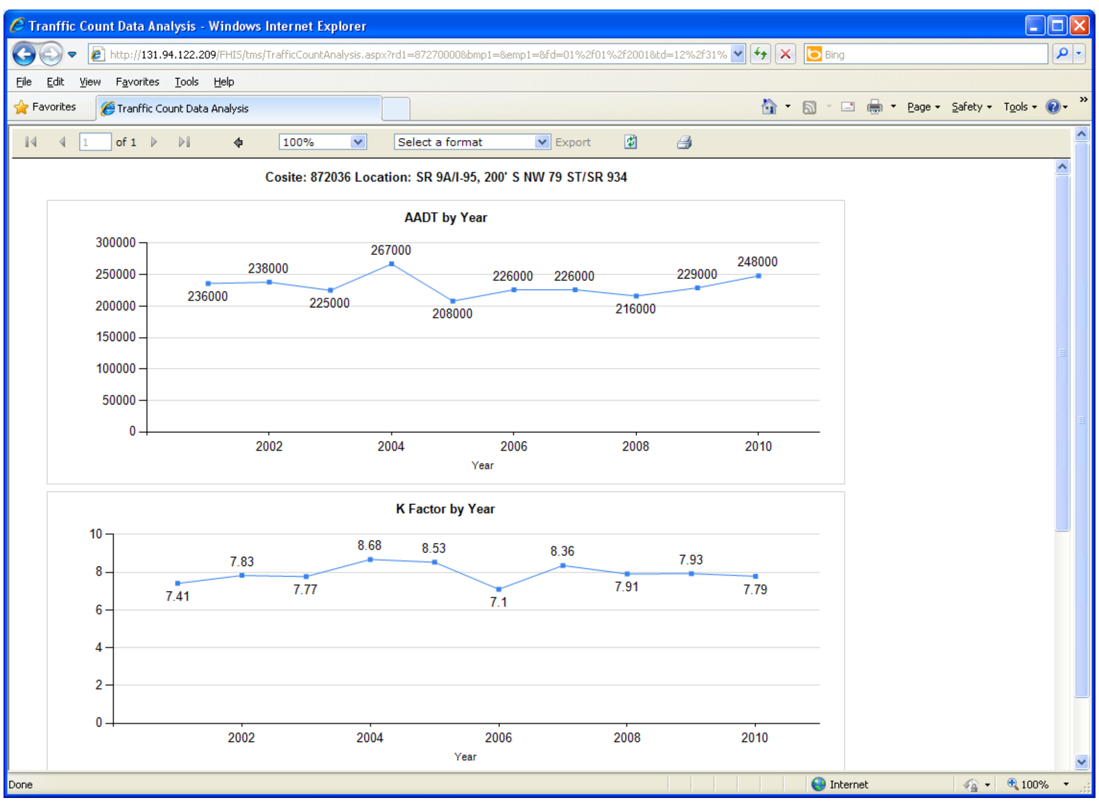


Figure 5-21 Traffic Count Trends (AADT and K Factor) at a Selected Site

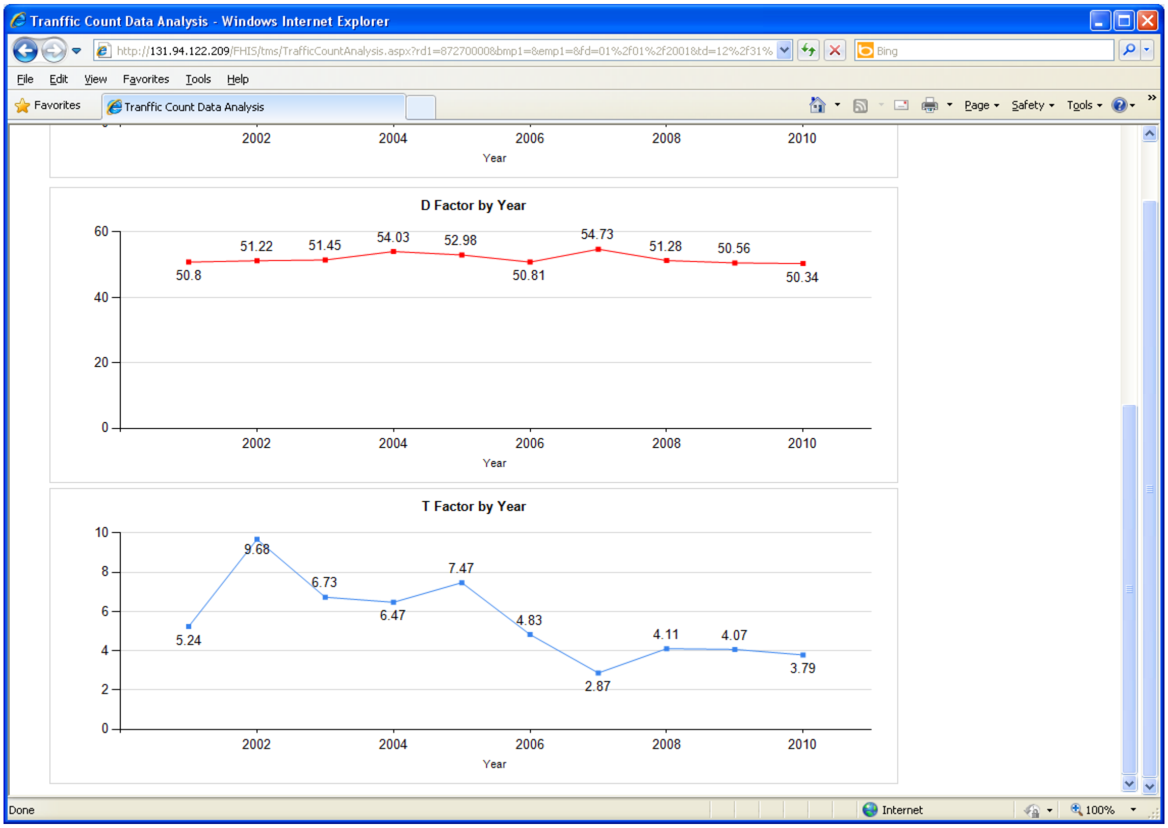
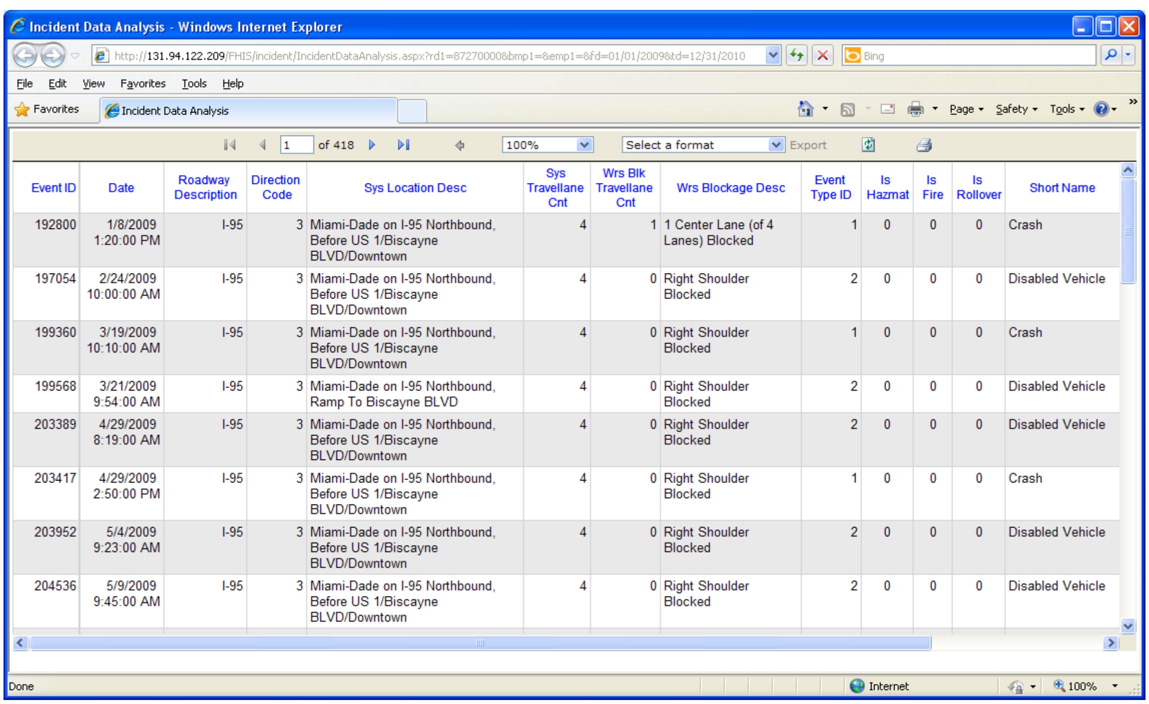


Figure 5-22 Traffic Count Trends (D Factor and T Factor) at a Selected Site

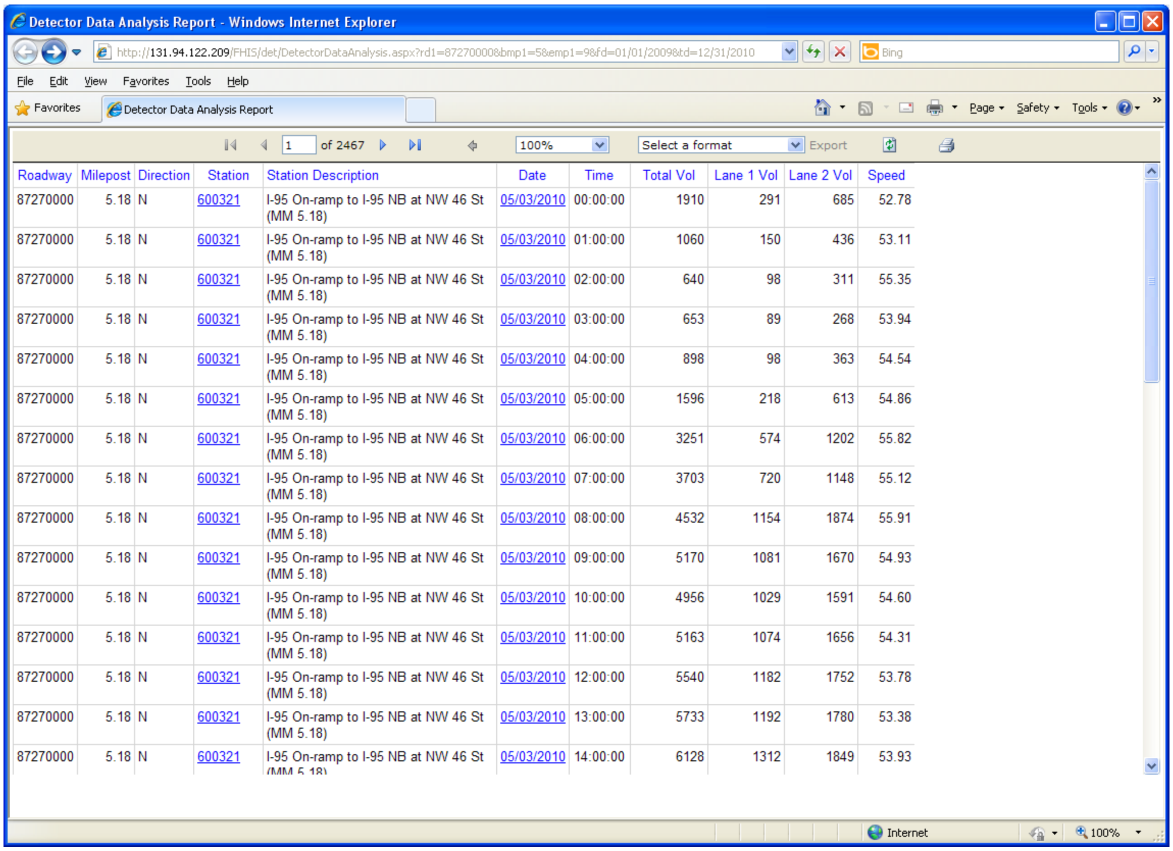


Event ID	Date	Roadway Description	Direction Code	Sys Location Desc	Sys Travellane Cnt	Wrs Blk Travellane Cnt	Wrs Blockage Desc	Event Type ID	Is Hazmat	Is Fire	Is Rollover	Short Name
192800	1/8/2009 1:20:00 PM	I-95	3	Miami-Dade on I-95 Northbound, Before US 1/Biscayne BLVD/Downtown	4	1	1 Center Lane (of 4 Lanes) Blocked	1	0	0	0	Crash
197054	2/24/2009 10:00:00 AM	I-95	3	Miami-Dade on I-95 Northbound, Before US 1/Biscayne BLVD/Downtown	4	0	Right Shoulder Blocked	2	0	0	0	Disabled Vehicle
199360	3/19/2009 10:10:00 AM	I-95	3	Miami-Dade on I-95 Northbound, Before US 1/Biscayne BLVD/Downtown	4	0	Right Shoulder Blocked	1	0	0	0	Crash
199568	3/21/2009 9:54:00 AM	I-95	3	Miami-Dade on I-95 Northbound, Ramp To Biscayne BLVD	4	0	Right Shoulder Blocked	2	0	0	0	Disabled Vehicle
203389	4/29/2009 8:19:00 AM	I-95	3	Miami-Dade on I-95 Northbound, Before US 1/Biscayne BLVD/Downtown	4	0	Right Shoulder Blocked	2	0	0	0	Disabled Vehicle
203417	4/29/2009 2:50:00 PM	I-95	3	Miami-Dade on I-95 Northbound, Before US 1/Biscayne BLVD/Downtown	4	0	Right Shoulder Blocked	1	0	0	0	Crash
203952	5/4/2009 9:23:00 AM	I-95	3	Miami-Dade on I-95 Northbound, Before US 1/Biscayne BLVD/Downtown	4	0	Right Shoulder Blocked	2	0	0	0	Disabled Vehicle
204536	5/9/2009 9:45:00 AM	I-95	3	Miami-Dade on I-95 Northbound, Before US 1/Biscayne BLVD/Downtown	4	0	Right Shoulder Blocked	2	0	0	0	Disabled Vehicle

Figure 5-23 Extracted Incident Records

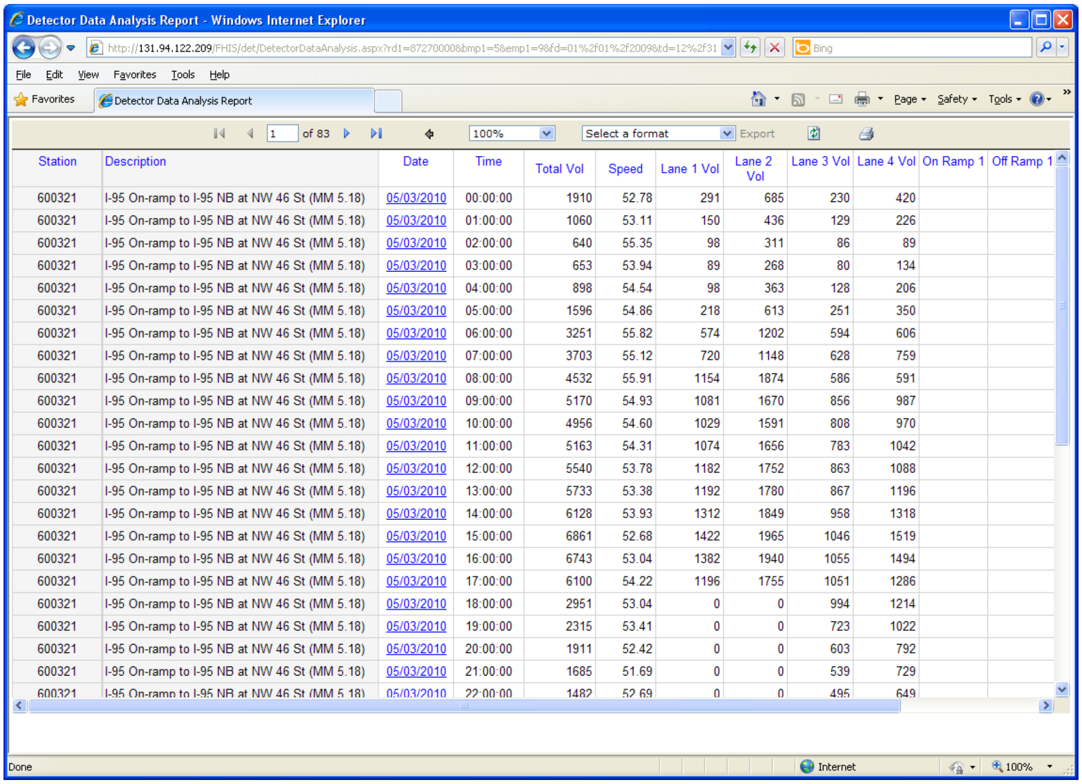
5.5.5. Detector Data Viewer

For most detectors, the 24 hour traffic volume and speed data are collected. In some cases, data are recorded every 12 hours, or even for shorter periods of time. The **Detector Data** viewer page lists the detailed traffic information for each selected detector station/site including the date, time, total traffic volume, traffic volumes on different lanes, and the average speed for this station. Figure 5-24 shows the data for all selected detectors on the I-95 corridor in Miami-Dade County. A detailed report on a specific detector/station ID will list traffic volumes and speeds for all dates and time points for the specific detector (see Figure 5-25). Figure 5-26 shows two line charts: total traffic volume and speed by time for a specific detector on a specific date.



Roadway	Milepost	Direction	Station	Station Description	Date	Time	Total Vol	Lane 1 Vol	Lane 2 Vol	Speed
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	00:00:00	1910	291	685	52.78
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	01:00:00	1060	150	436	53.11
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	02:00:00	640	98	311	55.35
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	03:00:00	653	89	268	53.94
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	04:00:00	898	98	363	54.54
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	05:00:00	1596	218	613	54.86
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	06:00:00	3251	574	1202	55.82
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	07:00:00	3703	720	1148	55.12
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	08:00:00	4532	1154	1874	55.91
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	09:00:00	5170	1081	1670	54.93
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	10:00:00	4956	1029	1591	54.60
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	11:00:00	5163	1074	1656	54.31
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	12:00:00	5540	1182	1752	53.78
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	13:00:00	5733	1192	1780	53.38
87270000	5.18	N	600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	14:00:00	6128	1312	1849	53.93

Figure 5-24 Detector Data Report Viewer



Station	Description	Date	Time	Total Vol	Speed	Lane 1 Vol	Lane 2 Vol	Lane 3 Vol	Lane 4 Vol	On Ramp 1	Off Ramp 1
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	00:00:00	1910	52.78	291	685	230	420		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	01:00:00	1060	53.11	150	436	129	226		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	02:00:00	640	55.35	98	311	86	89		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	03:00:00	653	53.94	89	268	80	134		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	04:00:00	898	54.54	98	363	128	206		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	05:00:00	1596	54.86	218	613	251	350		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	06:00:00	3251	55.82	574	1202	594	606		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	07:00:00	3703	55.12	720	1148	628	759		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	08:00:00	4532	55.91	1154	1874	586	591		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	09:00:00	5170	54.93	1081	1670	856	987		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	10:00:00	4956	54.60	1029	1591	808	970		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	11:00:00	5163	54.31	1074	1656	783	1042		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	12:00:00	5540	53.78	1182	1752	863	1088		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	13:00:00	5733	53.38	1192	1780	867	1196		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	14:00:00	6128	53.93	1312	1849	958	1318		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	15:00:00	6861	52.68	1422	1965	1046	1519		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	16:00:00	6743	53.04	1382	1940	1055	1494		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	17:00:00	6100	54.22	1196	1755	1051	1286		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	18:00:00	2951	53.04	0	0	994	1214		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	19:00:00	2315	53.41	0	0	723	1022		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	20:00:00	1911	52.42	0	0	603	792		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	21:00:00	1685	51.69	0	0	539	729		
600321	I-95 On-ramp to I-95 NB at NW 46 St (MM 5.18)	05/03/2010	22:00:00	1482	52.69	0	0	495	649		

Figure 5-25 Detector Data Report Viewer for a Selected Station

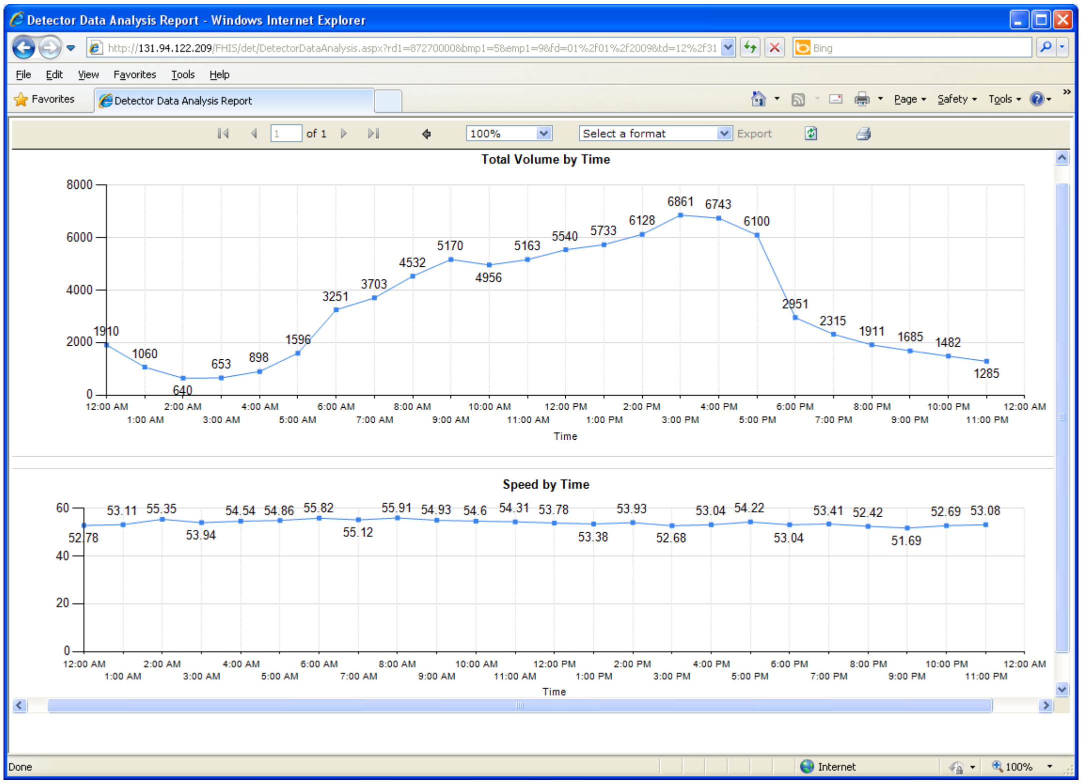
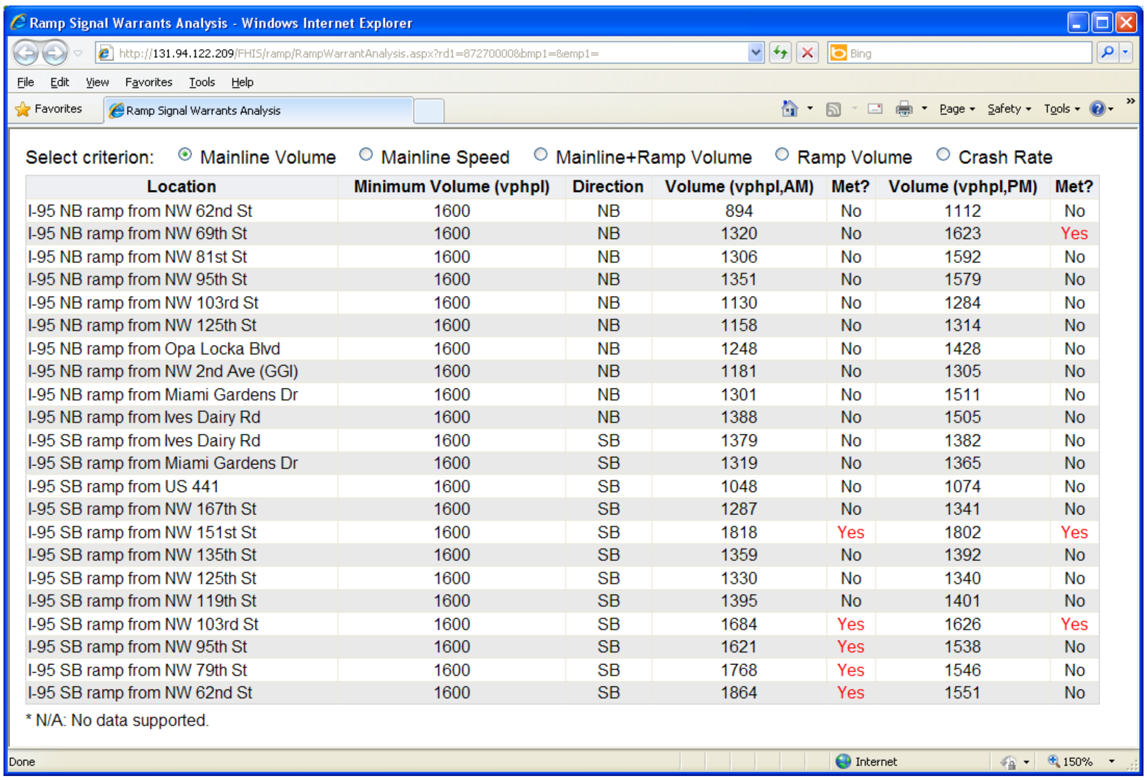


Figure 5-26 Line Charts: Total Volume and Speed by Time

5.6. Applications Menu

This menu is to list all the applications included in the system. Currently only the Ramp Signaling Warrant application for the evaluation of freeway corridors for potential ramp signaling is included.

As a result of a strong database platform, applications can be seamlessly integrated into the system. An application for the evaluation of freeway corridors for potential ramp signaling is built with the five criteria recommended in the previous chapter, i.e., mainline volume, mainline speed, mainline plus ramp volume, ramp volume, and crash rate. The other two criteria, ramp storage and length of acceleration lane, are not currently available due to the lack of the needed input data. Figures 5-27 through 5-31 show sample evaluation results based on the five different criteria, respectively, for a group of ramps along the I-95 corridor in Miami-Dade County.

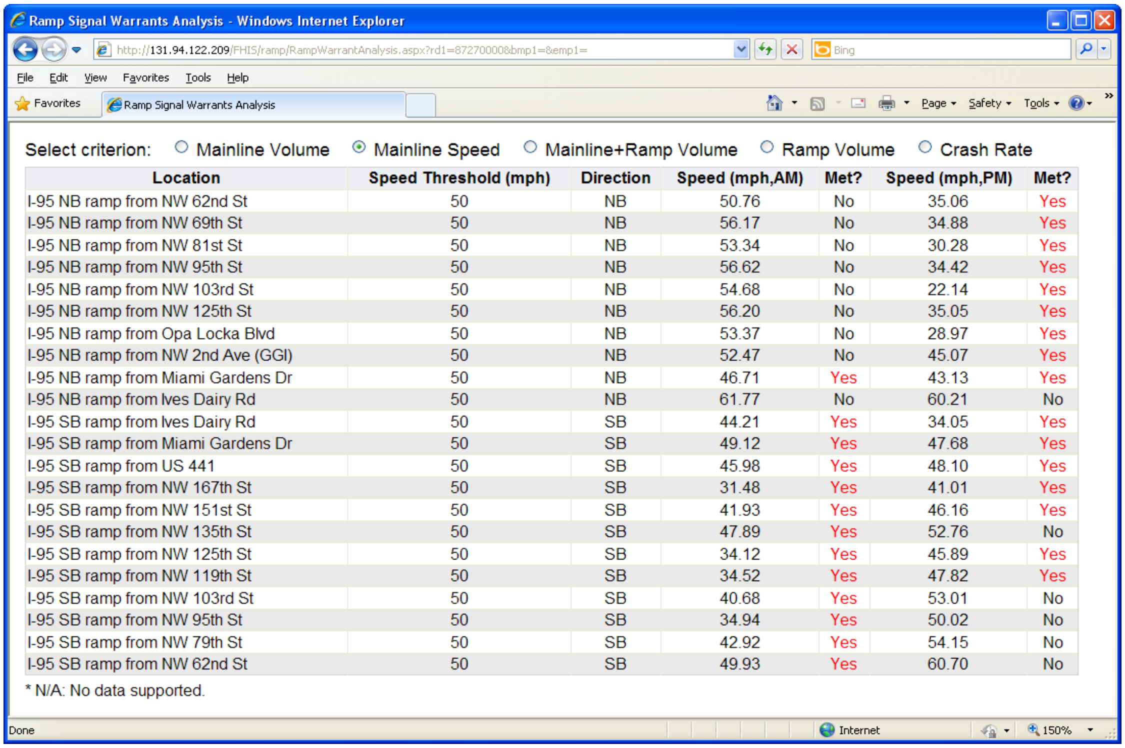


Select criterion: ◉ Mainline Volume ○ Mainline Speed ○ Mainline+Ramp Volume ○ Ramp Volume ○ Crash Rate

Location	Minimum Volume (vphpl)	Direction	Volume (vphpl,AM)	Met?	Volume (vphpl,PM)	Met?
I-95 NB ramp from NW 62nd St	1600	NB	894	No	1112	No
I-95 NB ramp from NW 69th St	1600	NB	1320	No	1623	Yes
I-95 NB ramp from NW 81st St	1600	NB	1306	No	1592	No
I-95 NB ramp from NW 95th St	1600	NB	1351	No	1579	No
I-95 NB ramp from NW 103rd St	1600	NB	1130	No	1284	No
I-95 NB ramp from NW 125th St	1600	NB	1158	No	1314	No
I-95 NB ramp from Opa Locka Blvd	1600	NB	1248	No	1428	No
I-95 NB ramp from NW 2nd Ave (GGI)	1600	NB	1181	No	1305	No
I-95 NB ramp from Miami Gardens Dr	1600	NB	1301	No	1511	No
I-95 NB ramp from Ives Dairy Rd	1600	NB	1388	No	1505	No
I-95 SB ramp from Ives Dairy Rd	1600	SB	1379	No	1382	No
I-95 SB ramp from Miami Gardens Dr	1600	SB	1319	No	1365	No
I-95 SB ramp from US 441	1600	SB	1048	No	1074	No
I-95 SB ramp from NW 167th St	1600	SB	1287	No	1341	No
I-95 SB ramp from NW 151st St	1600	SB	1818	Yes	1802	Yes
I-95 SB ramp from NW 135th St	1600	SB	1359	No	1392	No
I-95 SB ramp from NW 125th St	1600	SB	1330	No	1340	No
I-95 SB ramp from NW 119th St	1600	SB	1395	No	1401	No
I-95 SB ramp from NW 103rd St	1600	SB	1684	Yes	1626	Yes
I-95 SB ramp from NW 95th St	1600	SB	1621	Yes	1538	No
I-95 SB ramp from NW 79th St	1600	SB	1768	Yes	1546	No
I-95 SB ramp from NW 62nd St	1600	SB	1864	Yes	1551	No

* N/A: No data supported.

Figure 5-27 Example Evaluation Result based on Mainline Volume Criterion

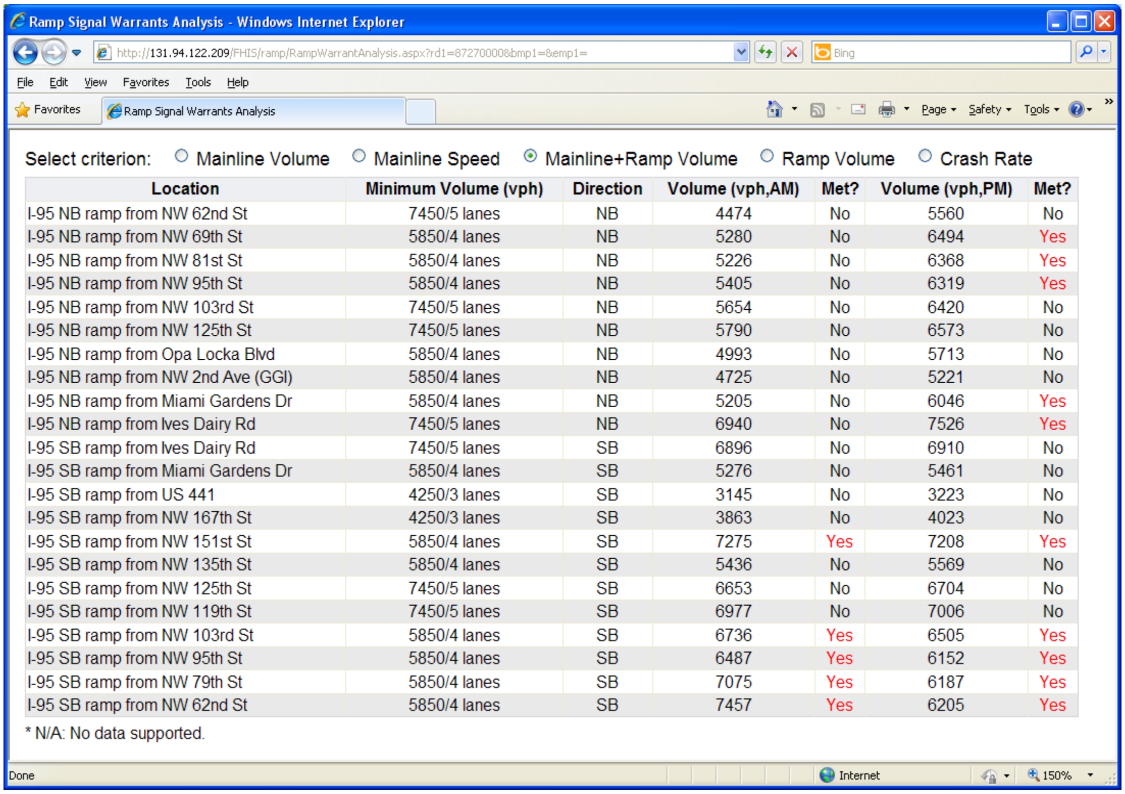


Select criterion: ○ Mainline Volume ● Mainline Speed ○ Mainline+Ramp Volume ○ Ramp Volume ○ Crash Rate

Location	Speed Threshold (mph)	Direction	Speed (mph,AM)	Met?	Speed (mph,PM)	Met?
I-95 NB ramp from NW 62nd St	50	NB	50.76	No	35.06	Yes
I-95 NB ramp from NW 69th St	50	NB	56.17	No	34.88	Yes
I-95 NB ramp from NW 81st St	50	NB	53.34	No	30.28	Yes
I-95 NB ramp from NW 95th St	50	NB	56.62	No	34.42	Yes
I-95 NB ramp from NW 103rd St	50	NB	54.68	No	22.14	Yes
I-95 NB ramp from NW 125th St	50	NB	56.20	No	35.05	Yes
I-95 NB ramp from Opa Locka Blvd	50	NB	53.37	No	28.97	Yes
I-95 NB ramp from NW 2nd Ave (GGI)	50	NB	52.47	No	45.07	Yes
I-95 NB ramp from Miami Gardens Dr	50	NB	46.71	Yes	43.13	Yes
I-95 NB ramp from Ives Dairy Rd	50	NB	61.77	No	60.21	No
I-95 SB ramp from Ives Dairy Rd	50	SB	44.21	Yes	34.05	Yes
I-95 SB ramp from Miami Gardens Dr	50	SB	49.12	Yes	47.68	Yes
I-95 SB ramp from US 441	50	SB	45.98	Yes	48.10	Yes
I-95 SB ramp from NW 167th St	50	SB	31.48	Yes	41.01	Yes
I-95 SB ramp from NW 151st St	50	SB	41.93	Yes	46.16	Yes
I-95 SB ramp from NW 135th St	50	SB	47.89	Yes	52.76	No
I-95 SB ramp from NW 125th St	50	SB	34.12	Yes	45.89	Yes
I-95 SB ramp from NW 119th St	50	SB	34.52	Yes	47.82	Yes
I-95 SB ramp from NW 103rd St	50	SB	40.68	Yes	53.01	No
I-95 SB ramp from NW 95th St	50	SB	34.94	Yes	50.02	No
I-95 SB ramp from NW 79th St	50	SB	42.92	Yes	54.15	No
I-95 SB ramp from NW 62nd St	50	SB	49.93	Yes	60.70	No

* N/A: No data supported.

Figure 5-28 Example Evaluation Result based on Mainline Speed Criterion

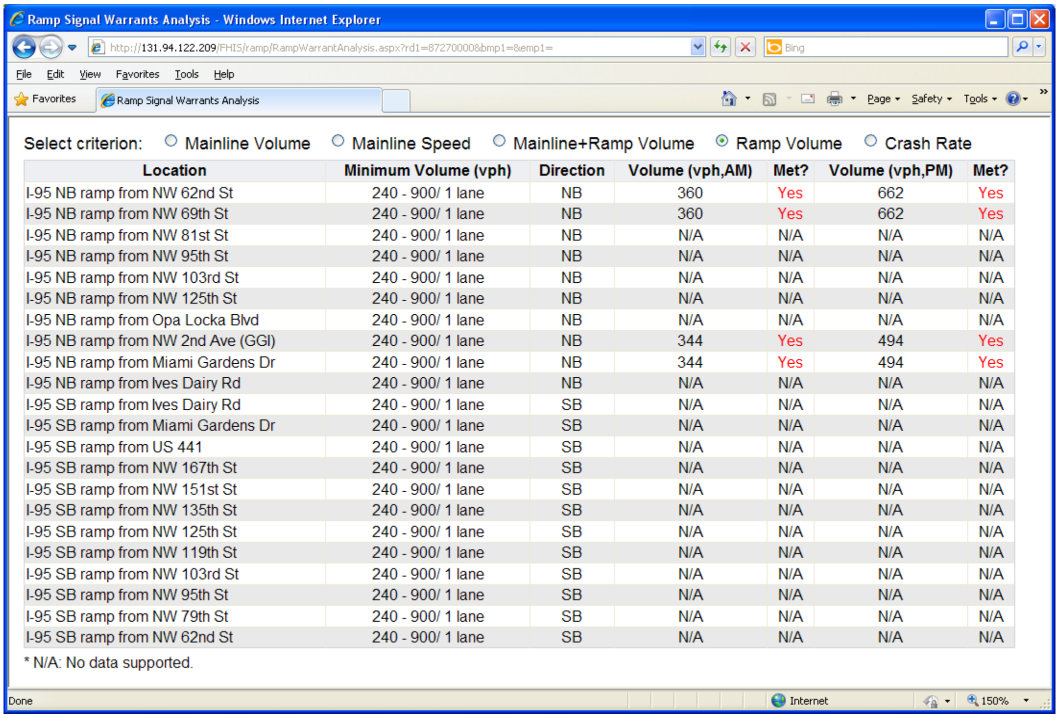


Select criterion: ○ Mainline Volume ○ Mainline Speed ● Mainline+Ramp Volume ○ Ramp Volume ○ Crash Rate

Location	Minimum Volume (vph)	Direction	Volume (vph,AM)	Met?	Volume (vph,PM)	Met?
I-95 NB ramp from NW 62nd St	7450/5 lanes	NB	4474	No	5560	No
I-95 NB ramp from NW 69th St	5850/4 lanes	NB	5280	No	6494	Yes
I-95 NB ramp from NW 81st St	5850/4 lanes	NB	5226	No	6368	Yes
I-95 NB ramp from NW 95th St	5850/4 lanes	NB	5405	No	6319	Yes
I-95 NB ramp from NW 103rd St	7450/5 lanes	NB	5654	No	6420	No
I-95 NB ramp from NW 125th St	7450/5 lanes	NB	5790	No	6573	No
I-95 NB ramp from Opa Locka Blvd	5850/4 lanes	NB	4993	No	5713	No
I-95 NB ramp from NW 2nd Ave (GGI)	5850/4 lanes	NB	4725	No	5221	No
I-95 NB ramp from Miami Gardens Dr	5850/4 lanes	NB	5205	No	6046	Yes
I-95 NB ramp from Ives Dairy Rd	7450/5 lanes	NB	6940	No	7526	Yes
I-95 SB ramp from Ives Dairy Rd	7450/5 lanes	SB	6896	No	6910	No
I-95 SB ramp from Miami Gardens Dr	5850/4 lanes	SB	5276	No	5461	No
I-95 SB ramp from US 441	4250/3 lanes	SB	3145	No	3223	No
I-95 SB ramp from NW 167th St	4250/3 lanes	SB	3863	No	4023	No
I-95 SB ramp from NW 151st St	5850/4 lanes	SB	7275	Yes	7208	Yes
I-95 SB ramp from NW 135th St	5850/4 lanes	SB	5436	No	5569	No
I-95 SB ramp from NW 125th St	7450/5 lanes	SB	6653	No	6704	No
I-95 SB ramp from NW 119th St	7450/5 lanes	SB	6977	No	7006	No
I-95 SB ramp from NW 103rd St	5850/4 lanes	SB	6736	Yes	6505	Yes
I-95 SB ramp from NW 95th St	5850/4 lanes	SB	6487	Yes	6152	Yes
I-95 SB ramp from NW 79th St	5850/4 lanes	SB	7075	Yes	6187	Yes
I-95 SB ramp from NW 62nd St	5850/4 lanes	SB	7457	Yes	6205	Yes

* N/A: No data supported.

Figure 5-29 Example Evaluation Result based on Mainline plus Ramp Volume Criterion

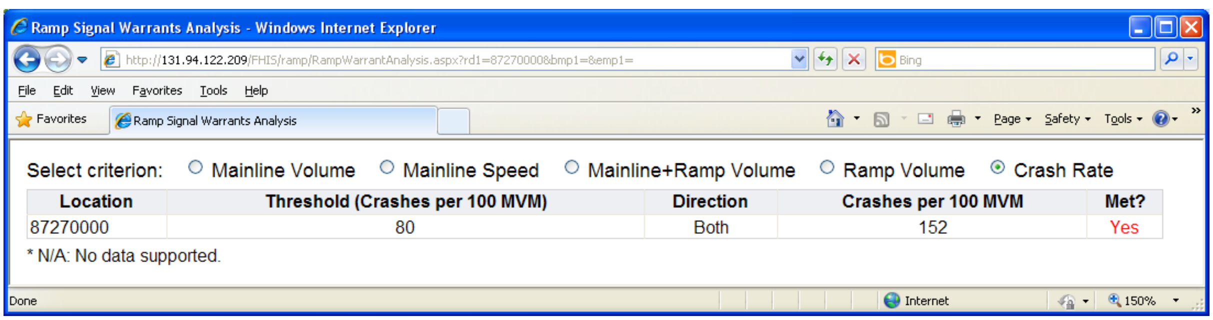


Select criterion: ○ Mainline Volume ○ Mainline Speed ○ Mainline+Ramp Volume ◉ Ramp Volume ○ Crash Rate

Location	Minimum Volume (vph)	Direction	Volume (vph,AM)	Met?	Volume (vph,PM)	Met?
I-95 NB ramp from NW 62nd St	240 - 900/ 1 lane	NB	360	Yes	662	Yes
I-95 NB ramp from NW 69th St	240 - 900/ 1 lane	NB	360	Yes	662	Yes
I-95 NB ramp from NW 81st St	240 - 900/ 1 lane	NB	N/A	N/A	N/A	N/A
I-95 NB ramp from NW 95th St	240 - 900/ 1 lane	NB	N/A	N/A	N/A	N/A
I-95 NB ramp from NW 103rd St	240 - 900/ 1 lane	NB	N/A	N/A	N/A	N/A
I-95 NB ramp from NW 125th St	240 - 900/ 1 lane	NB	N/A	N/A	N/A	N/A
I-95 NB ramp from Opa Locka Blvd	240 - 900/ 1 lane	NB	N/A	N/A	N/A	N/A
I-95 NB ramp from NW 2nd Ave (GGI)	240 - 900/ 1 lane	NB	344	Yes	494	Yes
I-95 NB ramp from Miami Gardens Dr	240 - 900/ 1 lane	NB	344	Yes	494	Yes
I-95 NB ramp from Ives Dairy Rd	240 - 900/ 1 lane	NB	N/A	N/A	N/A	N/A
I-95 SB ramp from Ives Dairy Rd	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from Miami Gardens Dr	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from US 441	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 167th St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 151st St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 135th St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 125th St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 119th St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 103rd St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 95th St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 79th St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A
I-95 SB ramp from NW 62nd St	240 - 900/ 1 lane	SB	N/A	N/A	N/A	N/A

* N/A: No data supported.

Figure 5-30 Example Evaluation Result based on Ramp Volume Criterion



Select criterion: ○ Mainline Volume ○ Mainline Speed ○ Mainline+Ramp Volume ○ Ramp Volume ◉ Crash Rate

Location	Threshold (Crashes per 100 MVM)	Direction	Crashes per 100 MVM	Met?
87270000	80	Both	152	Yes

* N/A: No data supported.

Figure 5-31 Example Evaluation Result based on Crash Rate Criterion

5.7. User Account Administration

FHIS provides the ability to restrict user access to certain data in the system. Currently, only crash records are restricted to authorized users. To access crash records in the system, a user must be provided by the system administrator with a login account. The user will be able to access crash records after logging onto the system by entering the username and password on the top right corner of the main screen. After logging in, access will be terminated either when the user clicks on the **Sign Out** link or when the session is timed out, which is set at 20 minutes.

To setup a user account, the system administrator will access the **User Account Administration** page by clicking the **Admin** link located also on the top right corner of the main screen. The page allows the system administrator to set up a new account and/or edit an existing account (including the deletion of accounts). Figure 5-32 shows the main screen of the page, which lists all the existing accounts.

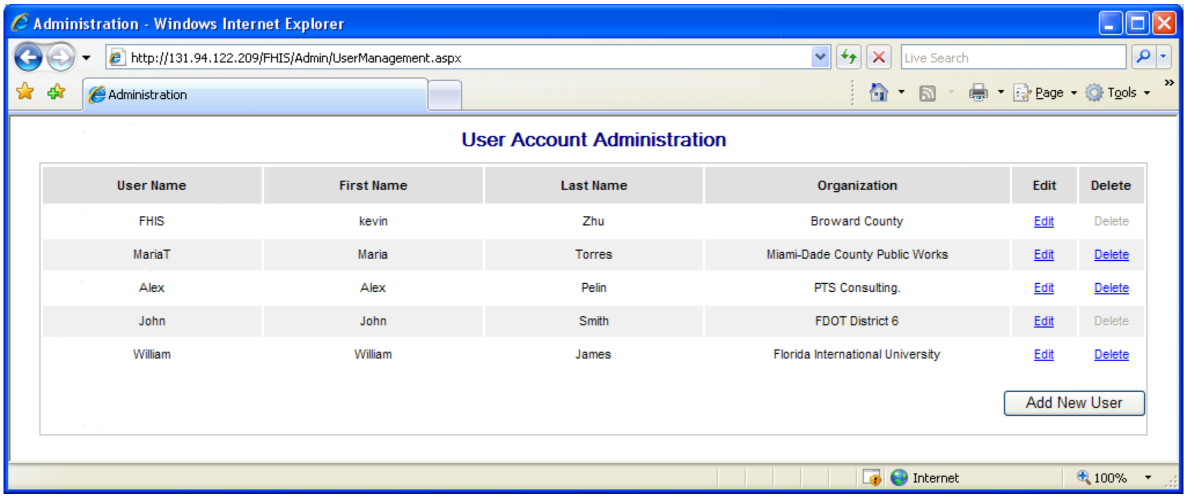


Figure 5-32 Main Screen of User Account Administration Page

To add a new user, the administrator clicks the **Add New User** button at the bottom right. This will open a yellow data entry area (see Figure 5-33) that allows a new account to be created. The administrator can then enter the first name, last name, organization, and email of the user, along with a username and a password assigned by the administrator. Both the username and password are not case-sensitive, and up to 20 alphanumeric characters may be specified for each. The administrator can then click **Add** to confirm the new user or **Cancel** to close the data entry area. The administrator can also click the **Edit** or **Delete** link next to each user account record to make changes to or delete an existing account (see Figure 5-34).

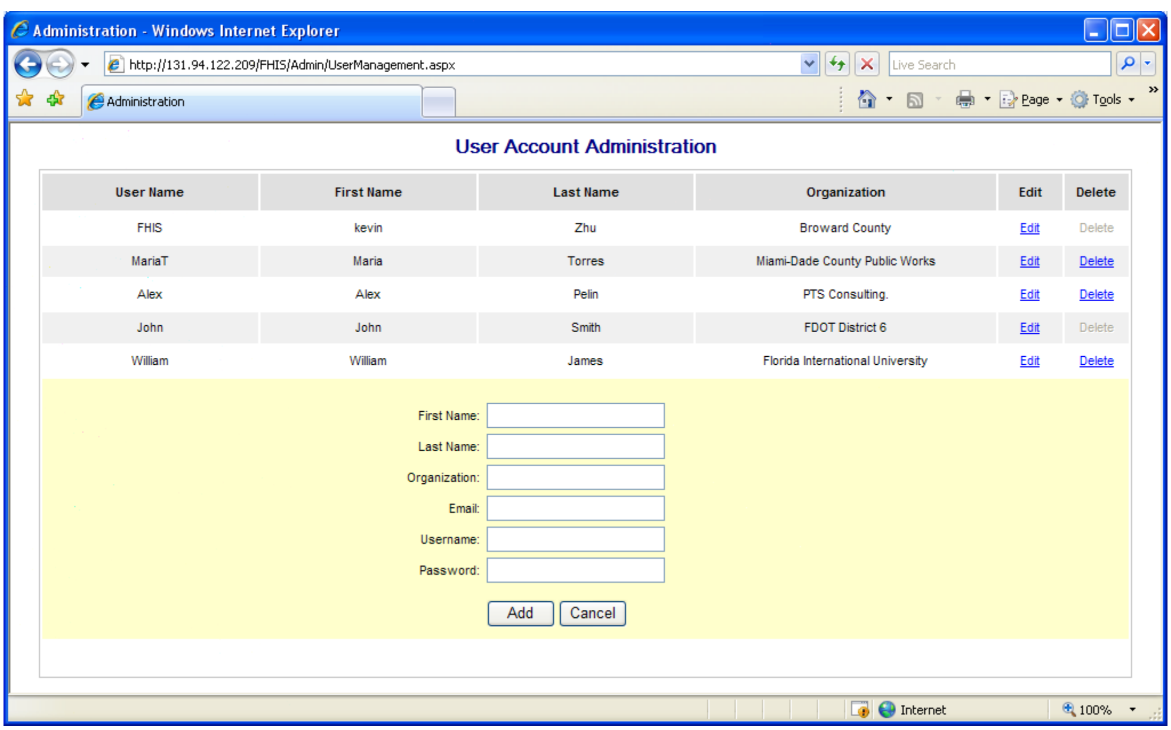


Figure 5-33 AddingNew User Account

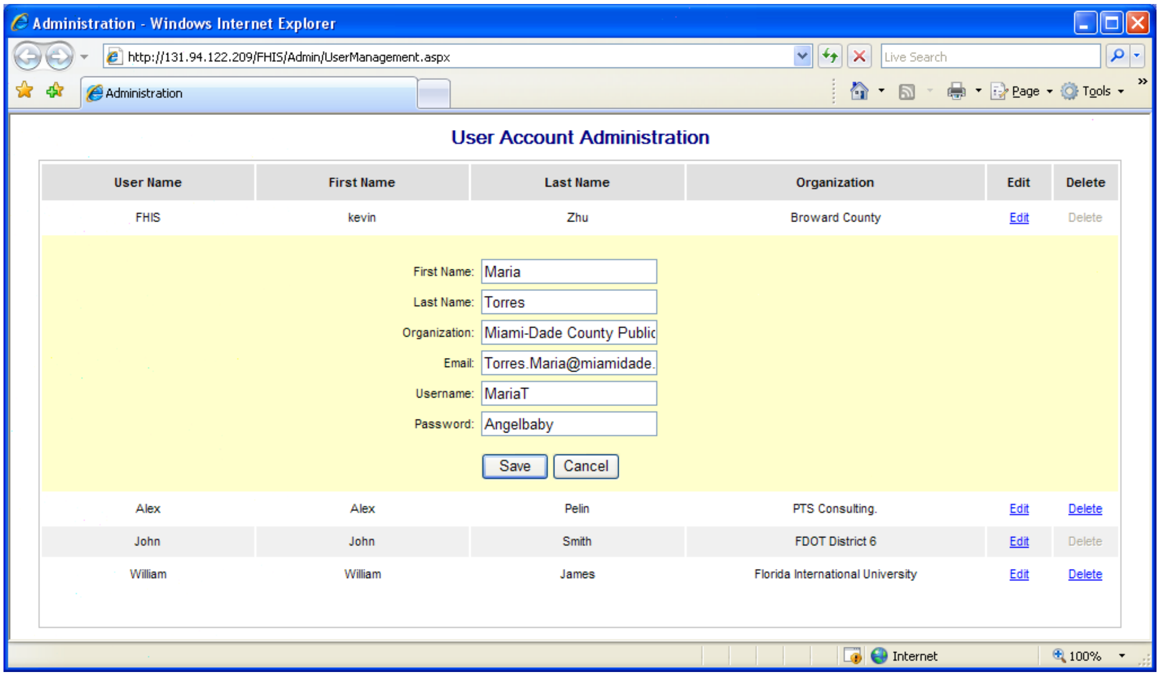


Figure 5-34 Editing a User Account

CHAPTER 6
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Ramp signaling is a traffic management strategy that installs traffic signals at freeway on-ramps to regulate the flow of traffic onto the freeway mainline. While studies have shown that ramp signaling helps alleviate traffic congestion and improve traffic safety, not all freeway facilities can benefit from ramp signal installation without incurring other problems such as excessive negative impacts on local arterials. Guidelines are thus needed to help transportation engineers and planners determine the suitability of specific corridors for ramp signaling. Proper evaluation of potential sites in accord with these guidelines requires the use of data sets currently maintained separately by various Florida Department of Transportation (FDOT) offices. The objectives of this study are thus to review existing ramp signal guidelines, evaluate and select those considered to be suitable for Florida's use, and then develop a computer system that applies these guidelines to assess the suitability of a select freeway location for ramp signaling.

To gain a good understanding of the current status of development for ramp signaling guidelines, the research team conducted an extensive review of the existing guidelines used for justification of ramp signaling. The extensive literature includes guidelines from 12 states in the U.S., four other countries, and three independent research organizations. Some of the key findings of this effort include:

1. There are very few published or formalized "warrants" that can be directly used for ramp signaling,
2. Development of a set of ramp signaling warrants is challenging because of the influence of multiple factors,
3. The existing individual warrants are both qualitative and quantitative, and
4. A systematic methodology is preferred when a set of individual warrants are available.

Five criteria were established to guide the evaluation and recommendation of individual guidelines. This is to ensure that the potential guidelines are not only appropriate, but also objective and can potentially be automated in a computer system. This study also compared similar criteria used by different agencies but with varying threshold values and conditions. To assess their effectiveness, several guidelines were applied on the existing ramp signaling sites on Interstate 95 in Miami-Dade County, Florida.

Based on the evaluation, seven guidelines were recommended for incorporation into the proposed system. These guidelines are grouped into three general categories in the form of warrants: traffic (warrants 1, 2, 3, and 4), geometric (warrants 5 and 6), and safety (warrant 7). Specifically, these warrants include:

1. Mainline peak hour volume > 1,200 vphpl.
2. Mainline peak hour speed < 50 mph.
3. For one-lane ramp, peak hour ramp volume is between 240 vph and 1,200 vph; and for multilane ramp, peak hour ramp volume is between 400 vph and 1,700 vph.
4. Total mainline volume and ramp volume is greater than the minimum threshold (depending on number of lanes) or the peak hour rightmost lane volume is greater than 2,050 vph.

5. Ramp storage distance is greater than the minimum requirement determined by the peak hour ramp volume.
6. Acceleration distance is greater than the minimum requirement determined by the freeway mainline prevailing speed.
7. Crash rate is greater than 80 per hundred million vehicle-miles.

Recognizing that each individual warrants may have different priority in justifying ramp signaling, a systematic procedure (in the form of a flow chart) is recommended.

After the guidelines in the form of warrants were selected, a web-based Geographic Information System (GIS), called the Florida Highway Information System (FHIS), was developed to automate, to the extent possible, the process of evaluating freeway sites for potential ramp signaling based on the selected guidelines. A major component of the system was a central database that integrates five independent data sets from different FDOT offices. The data sets included roadway inventory, detector data (including volume, speed, and occupancy), traffic counts, police crash records, and SunGuide incident records. The development of the web-based system greatly reduces the data acquisition effort, which is often the most time-consuming part of a project. The system can also be used as a tool for general data retrieval and serve as a general platform for implementing other potential applications.

The web-based GIS system has successfully combined the different data sources in an integrated database, implemented the functions for ramp signaling evaluation based on the selected guidelines, and provided functions for quick data retrieval and visualization. Further enhancements to the system could include adding (1) more data for additional details such as detector data in smaller time intervals (e.g., 15-minute), (2) additional visualization functions such as displaying crash locations on GIS maps, and (3) reporting functions that allow more flexible selection of variables that may come from multiple data tables.

Because the geometric data for ramp length and acceleration lane length are not directly available from FDOT’s Roadway Characteristics Inventory (RCI), warrants 5 and 6 as described above have not been implemented in this initial version of the system. These data may, however, be acquired through development of a combination of automated tools and manual processing, thus, making the evaluation of warrants 5 and 6 possible within the system.

Another enhancement to FHIS will be to work with the University of Florida (UF) researchers to access the STEWARD detector database directly. In this project, a tool was developed to automatically access the STEWARD data and integrate them into the FHIS system. This process, while proven to be feasible, is both slow and subject to server and network instability as well as changes to the STEWARD system made by UF. The direct data access option will avoid data duplication and save storage space on the local FHIS server. This is significant considering the large amount of detector data involved. The direct data access option will also allow FHIS to make use of the most current detector data available in STEWARD, with no data lead time.

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