A WEB-BASED GIS SYSTEM FOR RAMP SIGNALING EVALUATION

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ABSTRACT. This study attempts to develop a Geographic Information System (GIS) based system utilized in identifying ramp site that can potentially benefit from ramp signaling. To achieve this, this paper first identifies and evaluates existing ramp signaling guidelines, and then establishes a set of warrants with consideration for their appropriateness and the availability of the required data. A web GIS system is developed that integrates data required for ramp signaling justification from various databases that currently exist and operate independently. The established warrants are included in the system to ease the analysis. The interface and functions of the system are described in this paper, followed by a case study from a set of ramps along a segment of I-95 in Miami-Dade County in Florida.

Keywords: Ramp Signal Warrants, Database Design, Geographic Information System.

INTRODUCTION

In past decades, traffic congestion has placed a tremendous burden on freeways in most metropolitan areas throughout the country. The congestion causes delays and increases travel times, fuel consumption, emissions, etc. These issues, however, may be either difficult or infeasible to resolve with the construction or expansion of freeway facilities, due to reasons such as right-of-way constraints, financial difficulties, and/or political pressures. This has given rise to the use of low-cost traffic management techniques such as ramp signals (or ramp signaling).

Ramp signals are traffic signals installed at freeway on-ramps to regulate the flow of traffic on the freeway mainline. These signals can be set for different entering rates generated by a ramp-signaling algorithm (or a fixed-rate) to meter the ramp. The primary objectives (Balke *et al*., 2009) of ramp signals include:

1. Controlling the number of vehicles entering the freeway.
2. Reducing freeway demand.
3. Breaking up the platoons of vehicles released from upstream traffic signals.

Figure 1 shows a ramp signal implemented by the Florida Department of Transportation (FDOT) District 6. When activated, the signal alternates between green and red to the vehicle entering the freeway and allows it to smoothly merge in the mainline traffic.

Figure 1. A Ramp Signal Implemented by FDOT

In Florida, despite the newfound popularity of ramp signals, no ramp signal warrants or guidelines have been established. It is recognized not all freeway corridors can benefit from ramp signaling. 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. Thus, there is a need to establish some criteria to help transportation engineers and planners determine the suitability of specific corridors for ramp signaling.

This study aims at establishing a set of ramp signaling warrants mainly by identifying and evaluating existing guidelines for ramp signaling and then developing a GIS-based system that can be used to facilitate the evaluation of a freeway corridor for potential ramp signaling. The GIS system integrates several databases that contains data required for ramp signaling warrants and allows automatic data extraction for ramp signaling analysis.

EXISTING RAMP SIGNAL GUIDELINES AND WARRANTS

This section reviews the existing guidelines/warrants used for justifying the implementation of ramp signals in the US as well as in other countries. The purpose of this review is to gain a sound understanding of the state-of-the-practice in ramp signal warrants, capture valuable insights of ramp signaling justification criteria, and obtain ideas/inspiration on developing future ramp signaling warrants.

Ramp signaling guidelines from 12 states in the US (including Arizona, California, Texas, Utah, Wisconsin, etc.), 4 other countries, and 3 agencies were reviewed. The review findings are summarized below:

- There are very few published or formalized “warrants” that can be employed by a transportation planner/engineer, or a policy maker when attempting to determine whether the implementation of ramp signaling will be beneficial at a ramp location.
- Development of a set of ramp signaling warrants has proven challenging because of various factors involved. The justification of ramp signaling may depend on local conditions, which makes it even more difficult to identify transferable, uniformed warrants for ramp signaling.
- Among the few existing warrants, a number of individual warrants are quantitative and objective, while others are qualitative and subjective.
- 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, and to determine whether ramp signal installation is justified (ADOT, 2003).
- A majority of the 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 implementation is warranted (MUTCD, 2003).
- Some criteria used to warrant ramp signaling deployment are relatively easy to quantify. These criteria include those related to traffic such as mainline volume, ramp volume, and mainline speed, geometric such as ramp storage and length of acceleration lane (NDOT, 2006; AASHTO, 2004), and safety (e.g., crash rate).
- There are some other factors that should be considered in determining the implementation of ramp signaling (Jacobson, *et al.*, 2006; Burley and Gaffney, 2010). Most of these are either non-engineering related or difficult to quantify, and they include:
    - Availability of alternative routes
    - Type of corridor where ramp signaling is being deployed
    - Public acceptance
    - Enforcement
    - Funding

STATEGIES OF WARRANT SELECTION

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

1. The adopted warrant should promote the implementation of ramp signaling to mitigate recurring congestion on freeway mainline, especially congestion caused by excessive platoon entering from on-ramp and attempting to merge with mainline traffic,
2. The adopted warrant should promote the implementation of ramp signaling to address safety issue on freeway mainline, especially upstream of the candidate ramp and the vicinity of merging area,
3. 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,
4. The recommended threshold value in an individual warrant should be based on extensive review of previous experiences or an analytical process, and
5. The adopted warrant should be, to the extent possible, objective and easy to apply.

WARRANT RECOMMENDATION

This chapter recommends a set of Ramp Signaling warrants by evaluating the existing warrants with supplementary justification and reasoning and consideration of data availability. These recommended warrants are for application in Florida and are adopted in the GIS- based system.

These warrants recommended in this study are grouped into three categories: Traffic (warrant 1, 2, 3 and 4), Geometric (warrant 5 and 6) and Safety (warrant 7). Recognizing that the deployment of ramp signals must be preceded by a detailed engineering study, a ramp signal can be justified based on the following criteria:

- Warrant 1 - Mainline Volume: Ramp signaling is warranted at a location where the overall average mainline volume in peak hour is greater than 1200 vphpl.

- Warrant 2 - Mainline Speed: Ramp signaling is warranted at a location where the average mainline speed in 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 to 1200 vph
  b) For a ramp with more than one lane, ramp signaling is considered when the peak hour on-ramp volume is between 400 to 1700 vph

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

  Condition 1- the summation of peak hour mainline volume and ramp volume exceeds the following threshold values (UDOT, 2001; Enterprise, 2010):
    a) If there are two lanes, warrant is met when total volume is above 2,650 vph
    b) If there are three lanes, warrant is met when total volume is above 4,250 vph
    c) If there are four lanes, warrant is met when total volume is above 5,850 vph
    d) If there are five lanes, warrant is met when total volume is above 7,450 vph
    e) If there are six lanes, warrant is met when total volume is above 9,050 vph
    f) If there are more six lanes, warrant is met when total volume is above 10,650 vph

  Note that 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 a 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 formula below:

$$L = 0.82V - 0.00024342V^2$$

  where L is the required single-lane storage distance in feet, and V is the peak hour ramp demand in vph.

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

$$L = 0.14V^2 + 3.00V + 9.21$$

  where L is the required minimum acceleration distance in feet, and V is the freeway mainline prevailing speed in vph.

- Warrant 7: Crash Rate - Ramp signaling is warranted at a location where if the facility or roadway segment has a crash rate of higher than 80 accidents per hundred million vehicle miles (RHMVM) (WDOT, 2006). RHMVM is calculated using the following formula:

$$RHMVM = \frac{Number\ of\ Crash\ Yearly \times 100{,}000{,}000}{AADT \times 365 \times Distance}$$

  where,

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

Note that Warrants 1 through 6 can be applied for individual ramp locations, whereas Warrant 7 can only be applied to a facility or roadway segment with one or more ramps.

RAMP SIGNALING WARRANT PROCESS

The previous section identifies all the individual warrants recommended in this study. However, in most of the cases, not all warrants in a set have to be met before ramp signaling can be warranted. Also, certain warrants may have higher priority than others in determining the justification (e.g., safety concerns) such that ramp signaling may be deemed necessary by satisfying that particular criterion. To address these issues, a systematic methodology/process (typically formatted as a flow chart) is developed. The purpose of the warrant 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 incorporates the individual warrants in a process that balance both qualitative and quantitative conditions. Figure 2 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.

RAMP SIGNALING WARRANT SYSTEM

The proposed ramp signal warrants are implemented in a web-based GIS system called the Florida Highway Information System (FHIS). The system integrates data from various databases that currently exist and operate independently. This system not only provides database and GIS platforms on which applications can be built, i.e. an application for the evaluation of freeway corridors for potential ramp signaling, but also an analysis platform that helps transportation engineers and policy makers make decisions, in this application, for ramp signaling.

SYSTEM ARCHITECTURE

Figure 3 shows the FHIS architecture outline. The architecture 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 FHIS data and GIS services.

MAJOR DATA TABLES

A data table is a conceptual representation of the data structures that are required by a database. The present FHIS database server has two databases: a geodatabase named SDE and a traditional relational database named FHIS. SDE database contains the spatial data while FHIS includes integrated Roadway Characteristics Inventory (RCI) data, incident data, accident data, traffic count, and detector data. These data are converted into five core tables inside the current FHIS database. These tables are consolidated based on 8-digit roadway number and milepost (for specific point location, 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:

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

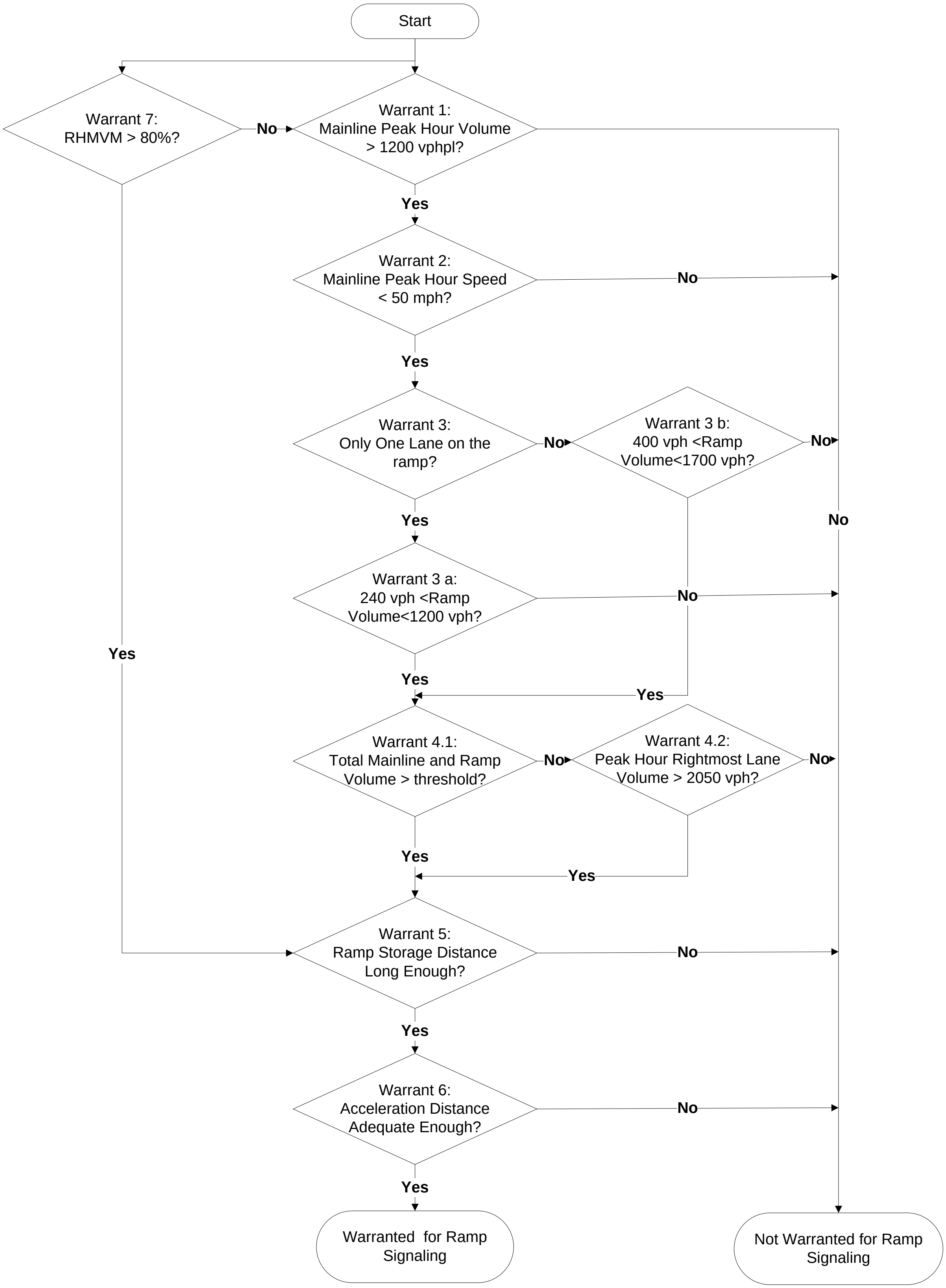


Figure 2. Ramp Signaling Justification Procedure

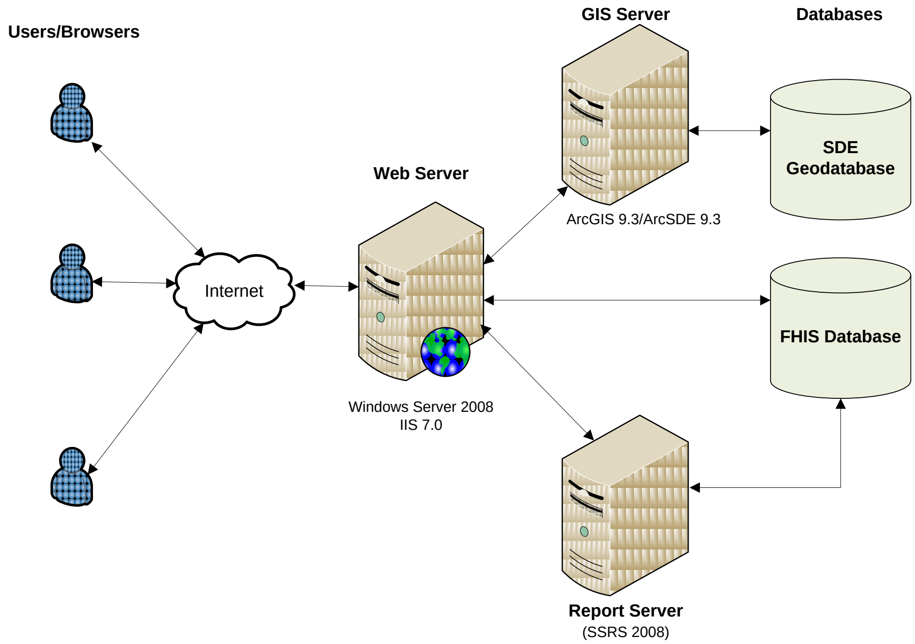


Figure 3. FHIS Architecture Diagram

2. *RCI data table:* The Roadway Characteristics Inventory table provides mainly roadway geometric information including number of mainline lanes, number of ramp lanes, lane width, acceleration lane length, ramp length, grades, existence of frontage roads, speed limits, etc.
3. *Detector data table:* Detector data are obtained from the STEWARD database system maintained by the University of Florida. A tool is 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, was brought into the FHIS detector data table.
4. *Traffic count table:* Traffic count data including AADTs, truck factors, K factors, and D factors at portable and permanent traffic monitoring sites, are also available in shapefiles at the FDOT site. These data are integrated into the FHIS database.
5. *Incident data table:* Freeway incident data are available from the SunGuide incident database. At first incidents are not associated to a roadway number and milepost for precise location identification. A GIS linear reference approach is used to identify the roadway number and milepost of from the locations' coordinates.

USER INTERFACE

Figure 4 shows the main application screen of this system. The screen forms the control center from which the users can easily query data and perform analysis with the help of inbuilt tools and menus. At the top of this center, there are seven main menus which enable users to perform GIS operations, data analysis and report services, and ramp signal warrants evaluation. On the left side panel, GIS layer legend is listed, followed by a few filters and textboxes to enable users to enter specific locations (roadway numbers and milepost ranges) for data query and analysis.

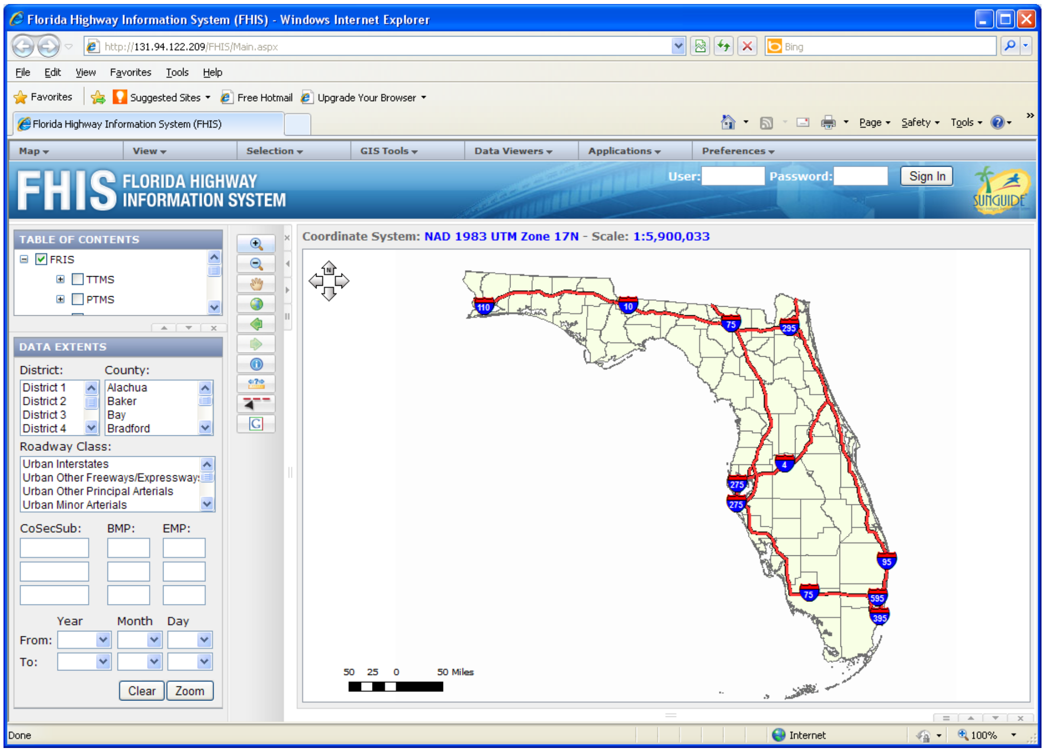


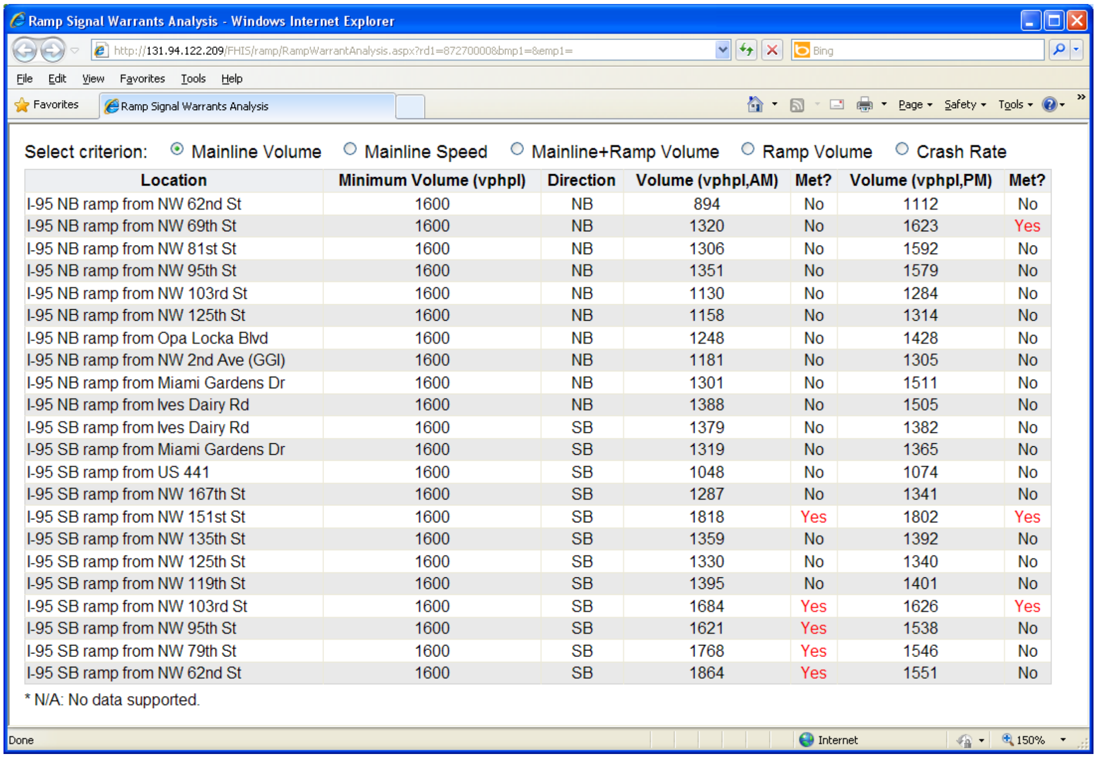
Figure 4. Main Application Interface

CASE STUDY

As a result of the strong FHIS 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 section: mainline volume, mainline speed, mainline plus ramp volume, ramp volume, and crash rate. The other two warrants are still under development at the writing of this paper. Figures 5 through 9 show example evaluation results for the five criteria, respectively, for a set of ramps along a segment of I-95 in Miami-Dade County, Florida.

SUMMARY

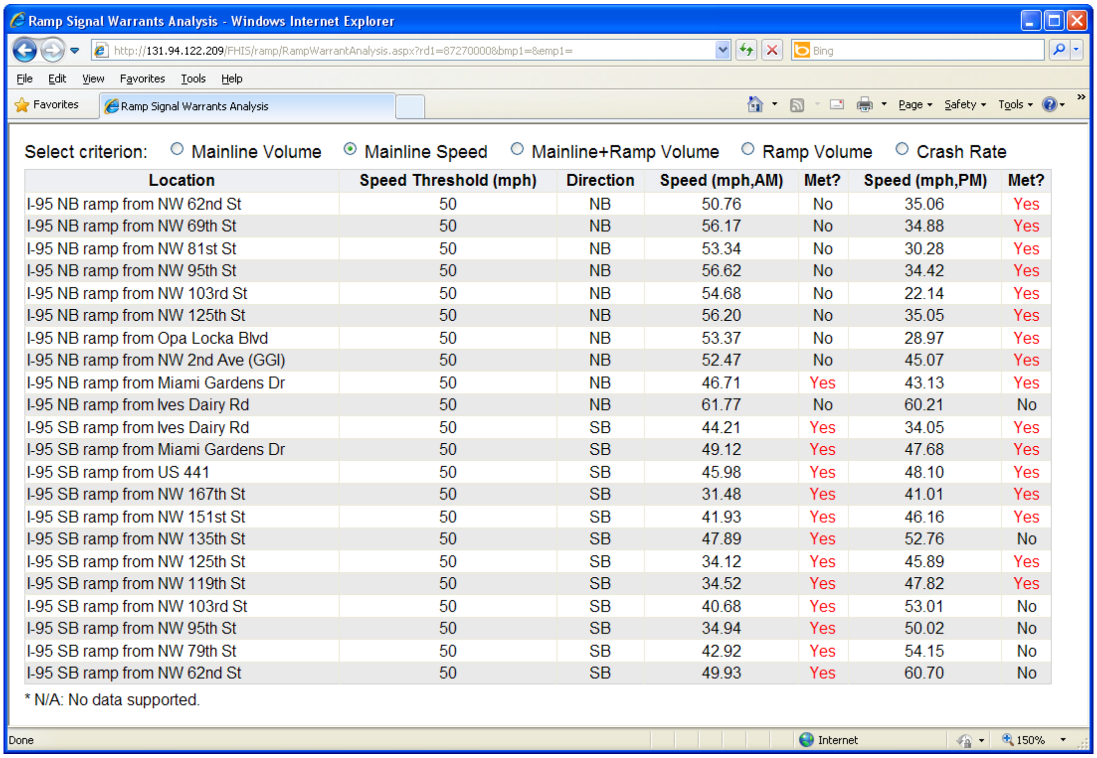
This paper has described an effort to develop ramp signaling warrants for Florida. The development was based mainly on the review and evaluation of existing warrants and guidelines from around the U.S. and other countries. A total of seven warrants were established based on five selection criteria. The selected warrants were implemented in a web Geographic Information System (GIS) that was designed to facilitate quick data retrieval and application of data for the warrant evaluation and analysis. The system integrates data required for ramp signaling justification from various databases that currently exist and operate independently. A case study based on a freeway corridor on I-95 in Miami-Dade County, Florida using the system was demonstrated.



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. Evaluation Result - Mainline Volume



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 6. Evaluation Result - Mainline Speed

Ramp Signal Warrants Analysis - Windows Internet Explorer

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 7. Evaluation Result - Mainline and Ramp Volume

Ramp Signal Warrants Analysis - Windows Internet Explorer

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 8. Evaluation Result - Ramp Volume

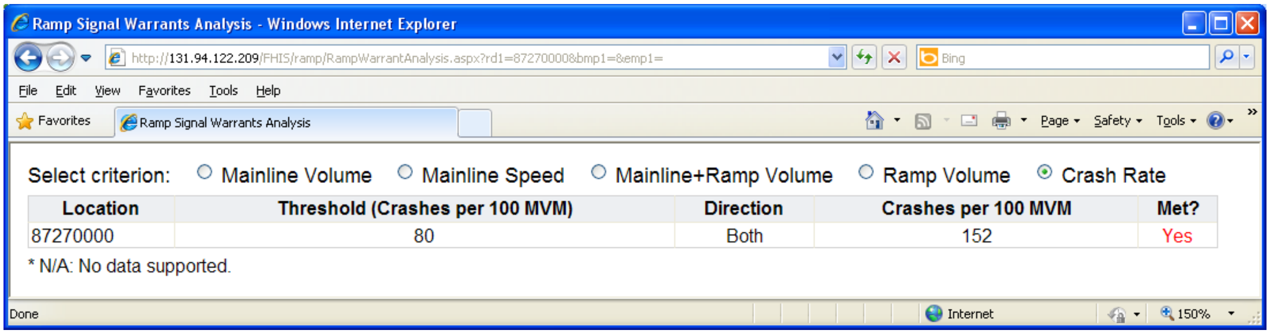


Figure 9. Evaluation Result – Crash Rate

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