



FLORIDA ATLANTIC UNIVERSITY
LABORATORY FOR ADAPTIVE TRAFFIC OPERATIONS & MANAGEMENT
in the College of Engineering & Computer Science

Final Report

Development of a Traffic Map Evaluation Tool for TMC Applications

Contract number: BDV27 TWO 977-12

June 2019

PREPARED FOR
Florida Department of Transportation



DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation (FDOT) or the U.S. Department of Transportation.

METRIC CONVERSION CHART

Approximate Conversions to SI Units				
Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
yd	Yards	0.914	meters	m
mi	Miles	1.61	kilometers	km
Area				
in²	square inches	645.2	square millimeters	mm ²
ft²	square feet	0.093	square meters	m ²
yd²	square yard	0.836	square meters	m ²
ac	Acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km ²
Volume				
fl oz	fluid ounces	29.57	milliliters	mL
gal	Gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m ³
yd³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
Mass				
oz	Ounces	28.35	grams	g
lb	Pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
Temperature (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
Force and Pressure or Stress				
lbf	Poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

Approximate Conversions from SI Units				
Symbol	When You Know	Multiply By	To Find	Symbol
Length				
mm	Millimeters	0.039	inches	in
m	Meters	3.28	feet	ft
m	Meters	1.09	yards	yd
km	Kilometers	0.621	miles	mi
Area				
mm²	square millimeters	0.0016	square inches	in ²
m²	square meters	10.764	square feet	ft ²
m²	square meters	1.195	square yards	yd ²
ha	Hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi ²
Volume				
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft ³
m³	cubic meters	1.307	cubic yards	yd ³
Mass				
g	Grams	0.035	ounces	oz
kg	Kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
Temperature (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
Illumination				
lx	Lux	0.0929	foot-candles	fc
cd/m²	candela/m ²	0.2919	foot-Lamberts	fl
Force and Pressure or Stress				
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in ²

TECHNICAL REPORT DOCUMENTATION

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Development of Traffic Map Evaluation Tool for TMC Applications (Final Report)		5. Report Date June 2019	
		6. Performing Organization Code	
7. Author(s) Aleksandar Stevanovic, Nikola Mitrovic		8. Performing Organization Report No.	
9. Performing Organization Name and Address Laboratory for Adaptive Traffic Operations & Management Florida Atlantic University 777 Glades Rd, Boca Raton, FL 33431		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. BDV27 TWO 977-12	
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee Street, MS 30 Tallahassee, FL 32399		13. Type of Report and Period Covered Draft Final Report, From January 2017 to June 2019	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract Traffic congestion is an inevitable part of urban transportation networks and its mitigation requires expertise (of Traffic Management Center operators) and proper detection coverage of the network. The traffic information is often collected with high temporal and spatial resolutions and retrieved from multiple sources. This project focuses on retrieval and analysis of traffic data from various sources and delivering this information, in form of a map, to traffic management operators. The online traffic platform, named Mapping Evaluation Tool (MET), has been developed. A variety of field traffic data were collected, processed, and analyzed. Multiple scripts are developed to populate the database within the MET. The methods are developed to perform trend-analysis and to infer meaningful statistics. The additional set of scripts is developed to allow an operator to run a variety of queries through a web interface. The extracted information is presented on the underlying maps and within the easy-to-read graphs. The proposed framework is robust and scalable enough to handle any data set that might be available in the future and to incorporate any additional performance metrics and graph representation.			
17. Key Words: traffic data, map, aggregation, visualization		18. Distribution Statement No restrictions.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 109	22. Price

ACKNOWLEDGEMENTS

The Florida Atlantic University research team acknowledges help and support from the FDOT and BCTED staff.

EXECUTIVE SUMMARY

Traffic-related information is often retrieved from multiple data sources and recorded, when possible, with high temporal and spatial resolutions. Most of the existing traffic platforms (e.g., Google Maps) analyze and process such data to deliver the user-based performance measures such as average travel time from point A to point B. On the other hand, the traffic operators (e.g. in Traffic Management Centers (TMC)) are interested in quickly spotting the congested sites in their networks, and understanding the trends of traffic conditions over a period of time. While the existing traffic platforms can reveal the congested sites (by observing the average speed along each facility), there are very few operator-friendly traffic platforms which can be used to develop a system-centric overview of traffic conditions.

The goal of this research project was to develop such a Mapping Evaluation Tool (MET) which can assist TMC operators to better monitor, analyze, and spot trends of arterial traffic operations. In short, the developed MET platform takes raw traffic data as inputs and produces the graphical and numerical forms of the relevant operator-based performance metrics as outputs. To address this goal, the FAU research team addressed several key objectives, which are listed below.

- 1) Develop analytical methods to report arterial performance measures and functional specifications for MET.

The novel methods are developed to help traffic operators better understand how real-time traffic information aligns with the relevant historical information. For instance, missing records of a traffic parameter, along a certain facility, for the last two months is a good indication that special attention needs to be given to this facility and its sensors. The additional methods are developed to present either real-time or historical traffic information in the context of common traffic parameters such as travel-time and speed. The special attention is given to the graphical representation of developed performance metrics on the underlying maps. The proposed performance measures are developed in such a way that they can be applied to multiple traffic parameters, both in arterial and highway operations.

- 2) Build a tool based on specifications and feedback from FDOT and other local agencies, along with an appropriate manual.

To address this objective FAU research team performed the following tasks.

- **Establish the Web-based Framework.** The MET is a complex traffic and geospatial platform whose operations are performed on both client and server sides. Multiple software applications are used to develop the MET tool and to establish smooth and efficient data transfer between client and server sides. FAU research team followed the state-of-the-art methods and recommended principles in building such web traffic platform and in the selection of the software tools used to build the MET platform.
- **Construct and Populate Traffic Databases.** Traffic data, collected from multiple sources and recorded with various temporal and spatial resolutions, are processed. FAU research team constructed the databases and populated them with historical information. Available real-time information is not just presented within the MET but also used to update the existing database. Special attention is given to developing underlying geospatial maps and accurately mapping the available data.

- **Construct and Test Flexible Queries.** In this context, multiple programming scripts are developed to compute proposed performance measures (developed within the first objective) for given databases and user-defined temporal and spatial restrictions. Noteworthy, the developed scripts are robust and scalable enough to perform numerous queries and aggregate the data on various temporal and spatial levels (link, corridor, and network).
 - **Deploy the Met on Personal Computer and Server.** The MET platform is installed on the personal computer and also tested on the MS Azure server. Various tests are performed to allow smooth and efficient operations on personal and server computers.
 - **Provide the Appropriate Manual.** All of the developed scripts are properly coded and commented to allow users to better understand the foundation of the MET. In addition, the MET functionalities and a brief description of how to use the tool are provided in the corresponding MET manual.
- 3) Test the tool, assess its ability to assist TMC operators and recommend potential future modifications.

The MET platform is developed and populated with traffic data. The MET scripts are written to enable a robust and flexible platform and to allow extensions of the tool in multiple directions. For instance, additional performance measures can be embedded in the tool. With little more effort, new data sets, and associated performance measures can be added to the MET in future.

As a part of the future steps, the FAU research team will meet with FDOT staff to discuss implementation opportunities of this project and potential upgrades of the existing MET tool. It is expected that this discussion will help FDOT to plan and identify the best options for the system implementations, and recommend modifications that need to be performed before the MET is deployed on an FDOT server.

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LIST OF ABBREVIATIONS (*alphabetical order*)

API – Application Programming Interface

BCTED – Broward County Traffic Engineering Division

BlueTOAD - Bluetooth Travel-time Origin and Destination

CDF – Cumulative Distribution Function

FDOT – Florida Department of Transportation

GPS – Global Positioning System

ITS – Intelligent Transportation Systems

LOS – Level Of Service

MET – Mapping Evaluation Tool

MVDS – Microwave Vehicle Detection System

OSM – Open Street Maps

PEMS – Caltrans Performance Measurement System

PM – Performance Measure

RITIS – Regional Integrated Transportation Information System

TMC – Traffic Management Center

TMC – Traffic Message Channels

1. INTRODUCTION

In the following text, motivation for this study is presented, major objectives are listed, and structure of the report is described.

1.1 Motivation

Traffic congestion is an inevitable part of urban transportation networks, and its mitigation strategies require the expertise of Traffic Management Center (TMC) operators and timely detection. However, an understanding of traffic performance, especially on arterial streets, and connecting this performance with potential causes is very challenging. One of the potential solutions is to utilize analytical methods and available traffic data.

With the recent development in sensor technologies, traffic data is nowadays collected on high temporal resolution from multiple sources in large traffic networks. The collected data have been used for numerous applications, especially in the context of Intelligent Transportation Systems (ITS). For instance, GPS (Global Positioning System) data from probe vehicles can help traffic operators and users (e.g., drivers) in travel time estimation between any two points in the network. More importantly, the collected data offer a great potential for traffic monitoring applications. In this regard, the collected data can help traffic operators better understand the traffic performance and match this performance with potential causes. To do so, the meaningful (and frequently derived) traffic information must be given to operators in an easy to understand way and systematically matched to the corresponding geographical location (or even a portion of the network).

Many analytical methods and algorithms have been used to process raw data and extract meaningful information. The extracted information is usually given in the form of derived performance measures such as estimated travel time, average speed, etc. These valuable data are delivered to the end-users (either operators or travelers) with the help of conventional map tool [1]. However, most of the available mapping tools either explicitly present the raw data on the underlying map (e.g., SunGuide platform) or focus on traveler-oriented performance measures such as travel-time estimation and route suggestions on Google Maps. On the other side, operators might need a mapping tool that can help them in monitoring everyday tasks, by:

- Matching the expected (or historical) and observed (real-time) performance measures (PMs)
- Identifying the potential causes for significant disagreement of observed and expected PMs
- Assigning the probabilities events of interests, such as having a railroad (or drawbridge) preemption at certain time
- Presenting all PMs in an easy-to-understand graphical form with the help of interactive tables and charts, etc.

Thus, there is a need to develop methods and tools that can both use a variety of data sources and robust trend-analysis mechanisms to aid traffic operators in the areas where the traffic congestion often occurs (either for recurring or nonrecurring reasons).

1.2 Project Objectives

The goal of this research project is to develop a Mapping Evaluation Tool (MET), which can help TMC operators to better monitor, analyze, and spot trends of arterial traffic operations. The tool will be built on common FDOT-approved framework and platforms, which will ensure consistency and lack of overlapping, along with other ongoing efforts. The tool is intended to cover a range of data and traffic monitoring procedures, which are either emerging (e.g., high-resolution controller data) or being slightly neglected in the other applications and tools (drawbridge and RR preemption data). The MET will be developed in close collaboration with FDOT D4 and potentially other districts and/or local traffic operations agencies in southeastern Florida. The goal is to build a tool robust enough to support daily utilization, trend analysis, and generation of customized reports. At the same time, the tool needs to be specifically developed for the TMC operators, and thus, it needs to be smaller in scope and oriented to meet specific needs and requests of operators overseeing arterial operations. This goal will be achieved by addressing following research objectives:

- Develop analytical methods to report arterial performance measures and functional specifications for MET.
- Build tool based on specifications and feedback from FDOT and other local agencies, along with an appropriate manual
- Test the tool, assess its ability to assist TMC operators, and recommend potential future modifications.

The emphasis of this research will be on the methods, alerts, and trend reports, which will help operators to better understand various impacts on arterial operations and utilize developed performance measures, monitoring procedures, methods, and thresholds for performance analysis in areas where we do not have good information (places without ITS and specific scenarios).

1.3 Structure of the Report

The goal of this project is development of a Traffic Evaluation Map (TEM) Tool for Traffic Management Center's Applications. In Section 2, we briefly review the relevant mapping tool platforms. In Section 3, we describe the experimental network and available data sources. In Section 3, we also describe the performance measures and analytical methods used in their derivation. In Section 4, we describe the key components and features of the Traffic Evaluation Map tool.

2. REVIEW OF THE SIMILAR PLATFORMS

In the following text, the other relevant mapping tools such as SunGuide, Google Maps, and RITIS are briefly reviewed.

2.1 SunGuide

SunGuide is a platform that has been used by the Florida Department of Transportation for monitoring everyday operations on arterials and highway segments that are covered by data-collection equipment. This equipment comprises Microwave Vehicle Detection System (MVDS) and BlueTOAD devices, as well as CCTV cameras. The traffic data, recorded from these sources, is presented in real-time to traffic operators with the help of an interactive map. The real-time data is updated every minute and can be presented in the reports generated for 15-min, hourly, or daily intervals. Some of the third party data are visualized on SunGuide without any explicit data analysis. Figure 2-1 shows the information that comes from MVDS stations that are presented on SunGuide. The key benefit of this platform is simplicity in presenting the relevant information on the map. However, the assortment of available performance measures and associated statistics are very limited. Furthermore, there is neither significant amount of data from other available data sources (e.g., RITIS, HERE) nor information about railroad preemption and drawbridge operations.

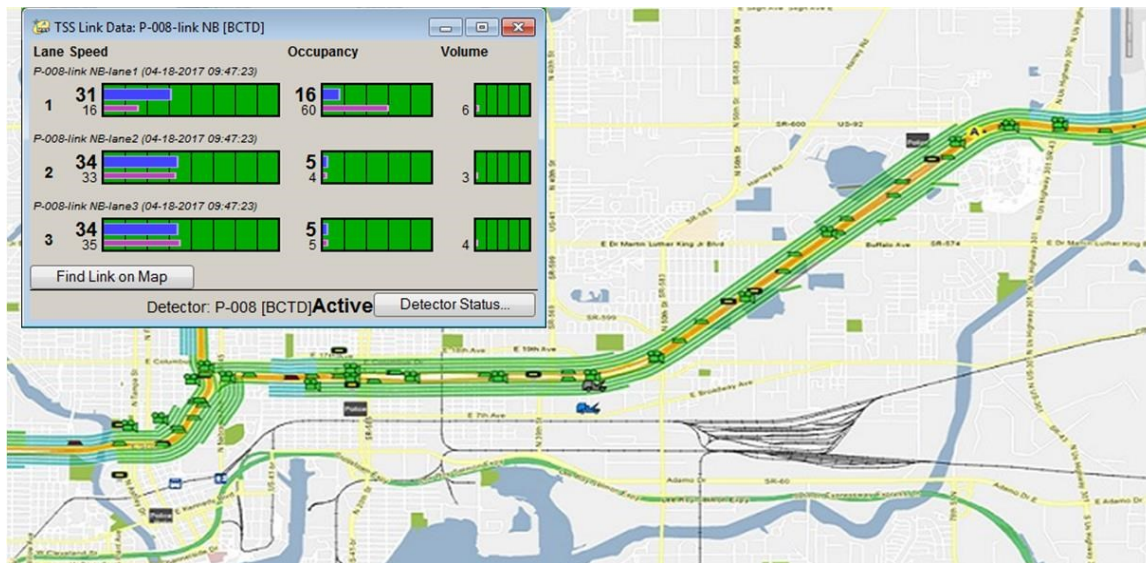


Figure 2-1: SunGuide Platform¹

¹ <http://lucentgp.com/?portfolio=florida-sunguide-software-support-maintenance-and-development>

2.2 Google Maps

Google Maps (see Figure 2-2) seems to be a dominant traffic tool used by most travelers. It collects traffic-related information from users of one of the available Google Services. In this way, a tremendous amount of traffic-related data has been continuously collected with the high temporal and spatial resolutions. Numerous analytical methods are used to extract meaningful user-related information [2-3]. For instance, the Google Maps framework provides information about current traffic (upper corner of Figure 2-2), estimates the travel time between any two points in the network (right), and delivers information about accidents and roadwork (bottom left corner of Figure 2-2). In addition, Google Maps contains a predictive analytics module that estimates and predicts travel times by leveraging significant historical databases (bottom left corner of Figure 2-2). The traffic-related information is often presented to users in a convenient way – on personal computers (left part of Figure 2-2) or on smartphones (right part of Figure 2-2). Most of the provided service is free, though certain data might be charged. For instance, a free Application Programming Interface API Key allows 2500 requests (e.g., for travel time estimation) per day. For additional requests, one would need a subscription for this Google service.

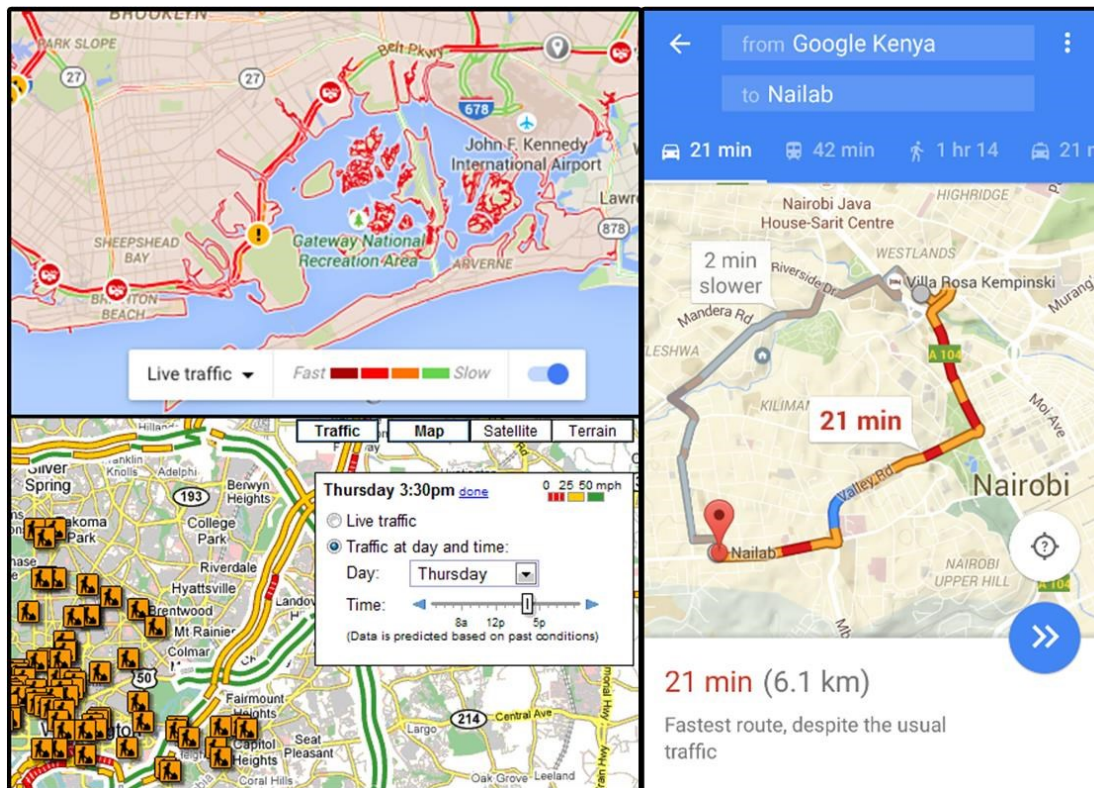


Figure 2-2: Google Map (GMaps) Tool²

² [http://www.potentash.com/2016/04/27/google-maps-traffic-alerts/;](http://www.potentash.com/2016/04/27/google-maps-traffic-alerts/)

<https://googlesystem.blogspot.com/2008/04/google-maps-predicts-traffic-conditions.html#gsc.tab=0>

2.3 Regional Integrated Transportation Information System (RITIS)

The Regional Integrated Transportation Information System (RITIS) uses heterogeneous traffic-related data from multiple sources to develop a significant database that is further used for research, planning, and operations purposes. The traffic-related data include (but are not limited to) information about the current traffic and incident sites, signal and parking related data, etc. These data are presented using innovative visualizations tool on the RITIS portal. In addition, the recorded data are achieved and often used to generate the historical reports. The visualization of real-time data and associated historical reports are available to the participating agencies, third parties, media, travelers, etc. Figure 2-3 shows the sources and application of the traffic related RITIS data (see Figure 2-3 top). It also shows a screenshot of the performance measures that might be generated on RITIS platform.

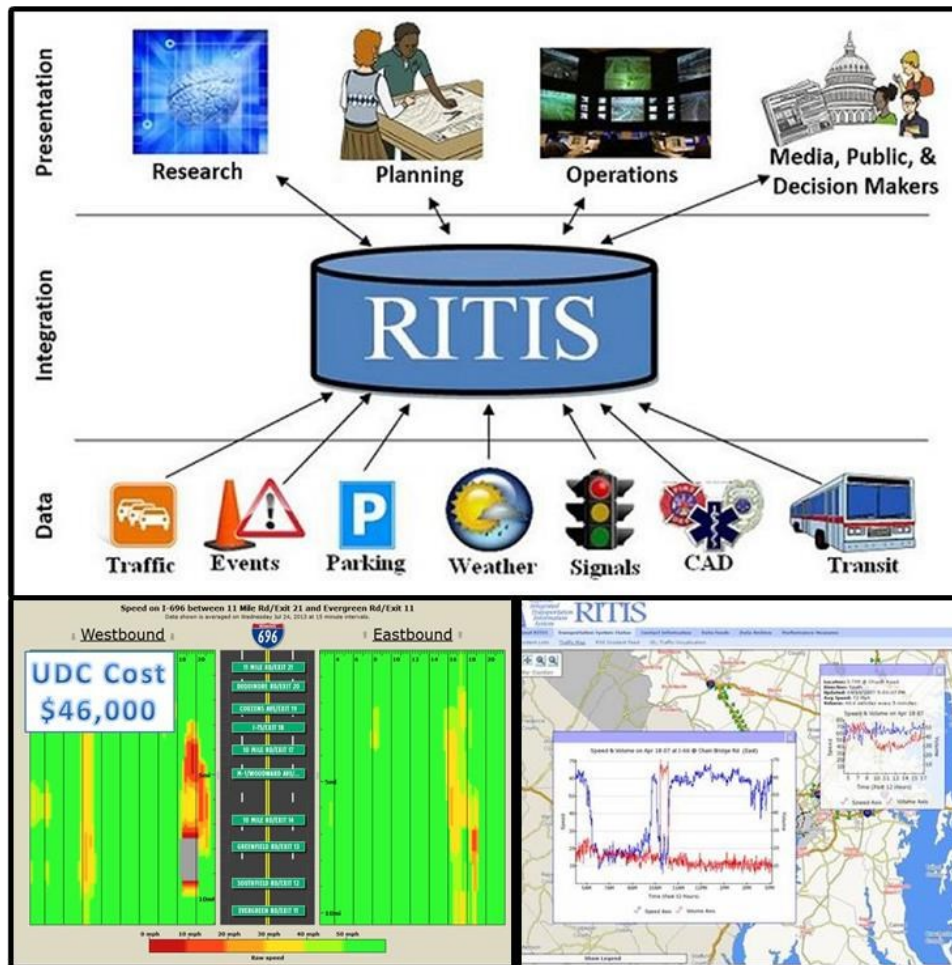


Figure 2-3: RITIS Tool³

³ Source: <http://i95coalition.org/projects/regional-integrated-transportation-information-system-ritis/>

2.4 Key Limitations of Existing Platforms

Some of the traffic platforms require special membership and are often fully available only to their customers (e.g., **ATMS.now**). On the other side, there are “open-source” platforms that are partially or fully available even for non-premium users. Also, most traffic platforms provide information from multiple sources (e.g., **Google Maps** or **Inrix**), while a few traffic frameworks (such as **Florida Traffic Online**) provide data from a limited number of sources.

Google Maps represents a limited source of both qualitative and quantitative data. They do not compare the real-time and historical information and do not provide historical analysis. Prediction applications are very limited since Google Maps heavily rely on historical information. For example, predicting traffic for a day or a week in advance does not seem to be very realistic due to inevitable and unpredictable fluctuations in traffic behavior. Google Maps provides user-related information, such as travel time estimation (for given origin and destination and mode). Hence, Google does not offer intersection and network based performance measure. In addition, historical reports cannot be generated using Google data due to the API restriction that Google imposes on all of its non-premium users. From the operator’s point of view, meaningful information is very limited to the use of different colors of the links (based on estimated travel time or speed) that describe various levels of congestions.

Similar to Google Maps, **Inrix** and **HERE** are major data providers who offer traveler-based service. In other words, Inrix and HERE utilize data from their users (e.g., through crowd-sourcing) and multiple sources to support accurate journey time, precise navigation and alternate route suggestion. Only a few of the available information can help traffic operators to better understand traffic behavior. One of them is travel time (or speed data) provided for the network segments or Traffic Message Channels (TMC). On the other side, Inrix and HERE platforms have similar limitations as Google Maps.

RITIS provides the large and diverse database, where most collected information is available in the form of historical reports. Only limited data sources are available in real-time. RITIS, similar to SunGuide, provides a significant amount of historical data (up to a few years back). However, the set of performance measures is often limited to hourly and daily projections of fundamental performance measures without any basic statistics associated with collected data. The reports (in terms of travel-time, congestion index, etc.) are often given for a customized set of links without any analysis of intersection-based performance. The collected data often require advanced (pre)processing techniques to extract meaningful information. For this reason, the relationship between recent and past traffic cannot be easily visualized and analyzed. RITIS does not provide any performance measures associated with the predictions, analytics of available CCTV video sources and traffic signal operations. In addition, the RITIS database does not deal with any railroad and drawbridge preemption operations, which are often seen as major causes of traffic disturbances (at links at the vicinity of rail-road and drawbridge crossings).

Caltrans Performance Measurement System (PEMS) is another traffic data warehouse that collects data from around 40,000 detectors (where most of them are on urban freeways). PEMS represents a visualization and analysis tool where the performance measures are presented on the single (freeway) link, route, and corridor or managed facilities. Most derived performance

measures are based only on detector data. Since the PEMS focuses on urban freeways, it does not consider the intersection and preemption (e.g., railroad crossings) operations. The PEMS also does not assign significant attention to traffic predictions and explicit comparison of the real-time and relevant historical information.

SunGuide is the existing mapping tool of FDOT that contains information collected from MVDS and BlueToad collections points. It explicitly visualizes the collected and third party data in real-time without any associated statistics. The information is often spatially presented only in the forms of TMC links and BlueToad segments. A similar type of information is presented in the historical reports where the data are usually aggregated on a daily basis. Hence, the presented performance measure cannot be easily applied for intersections and (sub)networks that contain multiple TMC links. In addition, SunGuide does not easily separate the recurrent (one that appears on a regular basis, i.e., every peak hour) and non-recurrent traffic congestion, and it often requires the operator's experience and expertise in dealing with the real-time MVDS and BlueToad data. Similar to RITIS, there are no predictive or CCTV video-related analytics embedded in the SunGuide platform. In additions, there are no performance measures associated with preemption operations and identification of distinctive traffic profiles. Finally, compliance of the real-time and historical data cannot easily be investigated.

In summary, there are several transportation platforms that collect traffic information and disseminate valuable statistics to operators and/or users. However, each of these platforms has several limitations that are carefully addressed in this study and embedded in the MET tool. In short, the MET tool can deal with the large and multiple data streams of real-time and historical information. More importantly, components of the MET tool provide predictive and video analytics of traffic parameters; while others focus on preemption operations. Real-time data is analyzed in conjunction with the representative historical information, while the operator-related performance measures are presented on an intersection- and network-level in addition to a common link-based level. In this way, the MET may overcome the existing limitations of alternative platforms (e.g., SunGuide, RITIS) and provide operators with an easy-to-use and efficient mapping tool.

3. ANALYTICAL METHODS AND PERFORMANCE MEASURES OF THE MAP EVALUATION TOOL

The robust Traffic Evaluation Map (TEM) Tool is designed for a specific study network (defined in Section 3.1) in a way that can be easily applied to any other area. The TEM tool is fed with historical and real-time traffic data from multiple sources (defined in Section 3.2). It is noteworthy that data availability might vary among different segments in the network (discussed in Section 3.3). In other words, both ITS-reach arterials and segments with no data will be carefully addressed. For all segments in the network, numerous performance measures (PM) will be properly described, documented, and presented on the map (see Section 3.4 for details). Various analytical methods are used to convert the provided (raw) traffic data into a helpful performance measure. These analytical methods lie at the core of the back-end component of our tool (described in Section 4). Another component of TEM will help operators visualize and

understand deliver information (usually in the form of derived PM). This component of the MET tool is referred as a front interface (described in Section 4).

3.1 Area network

Map Evaluation Tool (MET) will be developed for a heterogeneous network as depicted in Figure 3-1. The sizeable test network contains freeway and arterial links as well as moveable drawbridges and railroad crossings. The study network is located in the Broward County (south Florida), and it occupies an area of approximately 140 square miles. The study network is bordered by Commercial Blvd. on the north, A1A on the east, Griffin road on the south, and I-75 on its west side (see the green line in Figure 3-1).

Significant traffic might be expected throughout the year, especially from August until June. Most of the travelers are commuters, who in this part of Florida often use their private car to execute trips. The average occupancy of vehicles in SE Florida is quite low for both private- and public-transport vehicles. The climate is humid subtropical and rainfall season is from May through October.

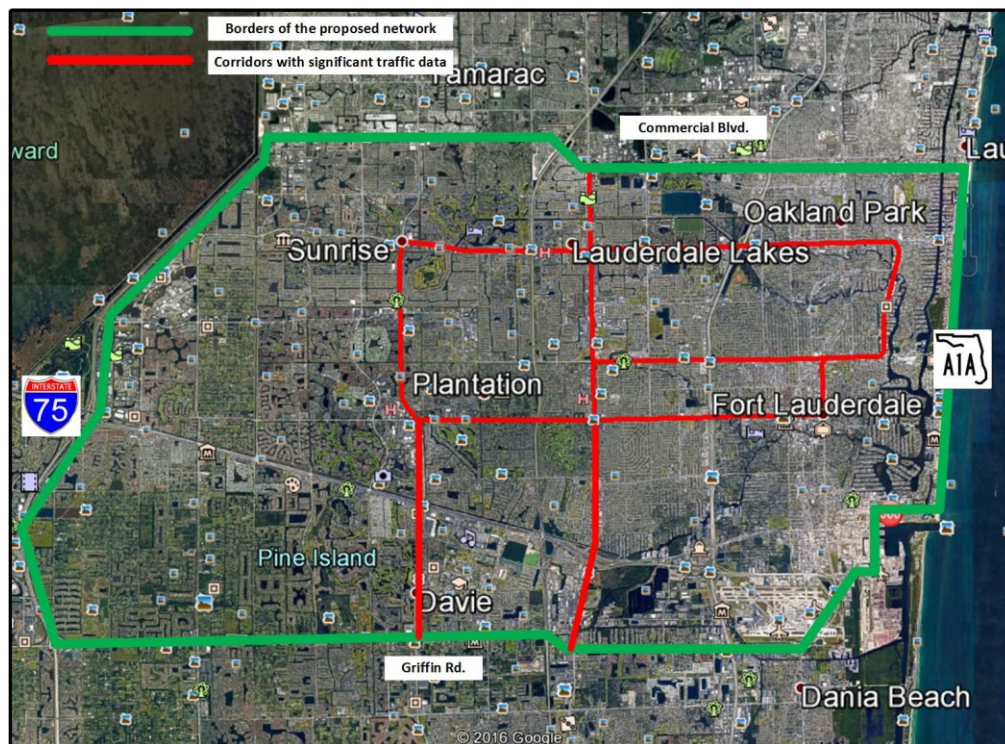


Figure 3-1: Study Area Network

3.2 Sources of Traffic Data

Traffic-related data from multiple sources is utilized in developing the MET. Table 3-1 lists the data types and their sources. Table 3-1 also shows the frequency and level of aggregation of

available data. On Table 3-1, some of the recorded data is available in (close) to real-time, while others are available only in the form of historical traffic information. In the context of spatial resolution, traffic information might be recorded at a certain point (or node), intersection approach, or segment (see Table 3-1). Network performance will be aggregated based on the segment- and point-based measurements. These segment and point-based measurements might be available only for arterial segments (e.g., RR preemption) or for both arterial and freeway network (e.g., volume obtained from MVDS devices (see Table 3-1 for more details)). In the following section, the used sources and technology to collect the data are briefly explained.

3.2.1 Microwave Vehicle Detection System (MVDS technology)

The study network is partially equipped with MVDS technology for collecting traffic data (see Figure 3-2). MVDS is a microwave vehicle detection system that uses a Federal Communications Commission (FCC) certified, low-power microwave radar beam to detect vehicle presence and generate volume, occupancy, and speed data. Traffic volume is defined as the number of vehicles that pass a particular point (or line) on a highway during a specified time interval. Speed, obtained from MVDS station, is a point or node-based speed. This speed represents the average speed of all detected vehicles during a specified time interval. Occupancy is defined as the percent (or portion) of time the detection zone of a detector is occupied by some vehicle. For a specific time interval, occupancy is the sum of the time that vehicles cover the detector divided by that specific time interval. Occupancy is influenced by vehicle speed, vehicle length, and detector length.

It is noteworthy that the reported speed at MVDS stations has been projected in 1-mile segments and used to compute the travel time. However, travel time estimated in this way is not highly reliable and will not be considered in this study. Instead, a more reliable travel times will be obtained through BlueTOAD devices and from RITIS databases.

Table 3-1: Available Data Sources

Data Type	Source	Aggregate Interval - Real Time Data	Aggregate Interval – Hist. Data	Freeway	Arterial
Volume	SunGuide (MVDS)	1-min	15-min	P	P
Speed	SunGuide (MVDS)	1-min	15-min	P	P
Occupancy	SunGuide (MVDS)	1min	15 min	P	P
AADT	FL Traffic Online	-	-	P	P
Travel Time	SunGuide (BlueTOAD)	1-min	15-min	S	S

Travel Time	RITIS	-	1 to 60-min	S	S
Travel Time	Google	Instantaneous		S	S
Video data	CCTV Cameras	Instantaneous		A	A
Incident Reports	SunGuide			P	P
Traffic Signal data	ATMS.now		Per-cycle, in the form of split history & alarm rep.	P	P

P – Point (Node) S – Segment A - Approach

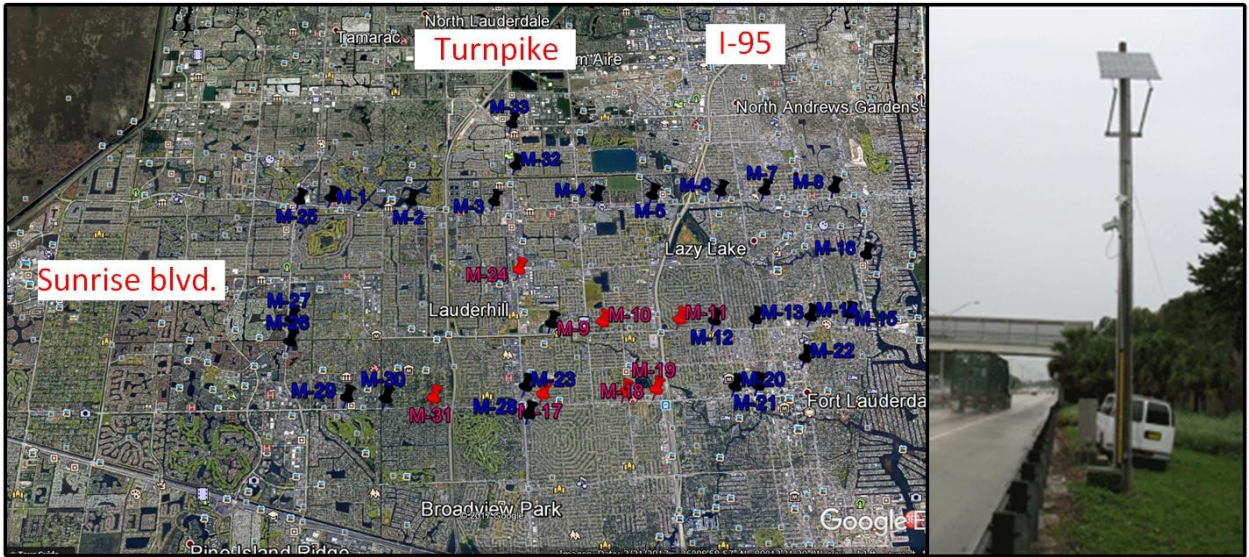


Figure 3-2: Location of the MVDS Stations in the Study Area Network

3.2.2 Bluetooth Travel-time Origin and Destination (BlueTOAD)

BlueTOAD technology measures travel times between predefined sets of Bluetooth sniffing devices. These devices represent virtual origin-destination pairs in the network, which are used to detect anonymous Bluetooth signals broadcasted from traveler’s devices. Noteworthy, BlueTOAD records the MAC address of the detected devices (within vehicles) and time of signal detection. By matching the MAC address in the recorded database, one can estimate the driver’s travel time by considering only detection times at origin and destination (BlueTOAD) stations. The average travel time of a particular segment is estimated by taking the information from all Bluetooth devices into account (from the recorded database). Corresponding speed is calculated as the ratio of the travelled distance (between origin and destination) to taken time, estimated by BlueTOAD technology. Figure 3-3 shows the location of BlueTOAD stations in study network.

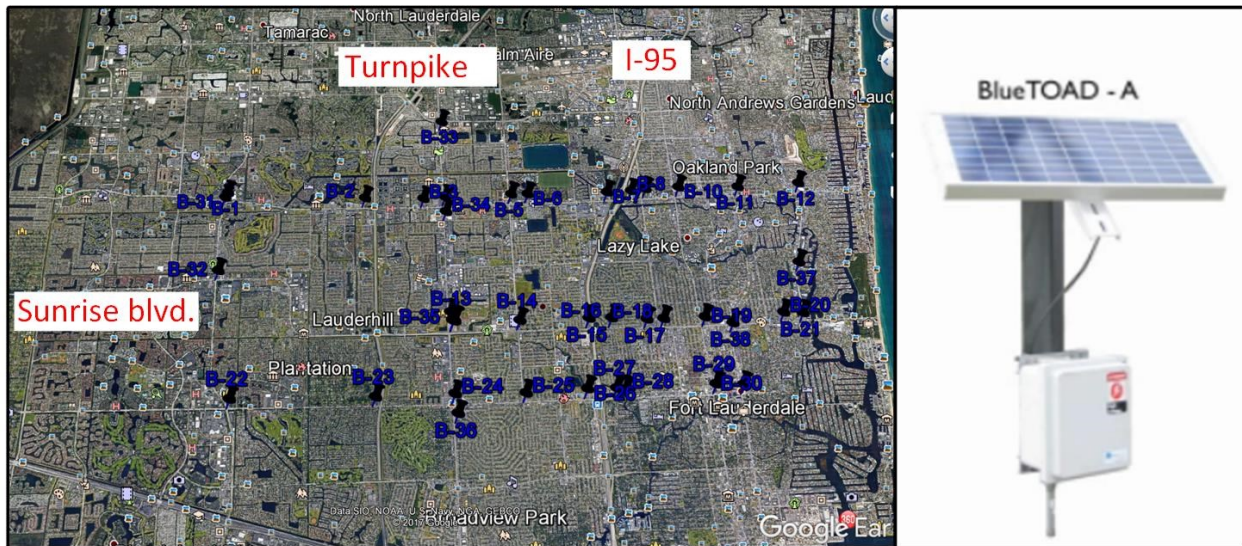


Figure 3-3: Location of the Blue Toad Stations in the Study Area Network

3.2.3 Regional Integrated Transportation Information System (RITIS)

The Regional Integrated Transportation Information System (RITIS) is an automated data fusion and dissemination system that provides an enhanced overall view of the local transportation network. Figure 3-4 shows the Data Analytics Suite interface of the RITIS platform. The RITIS platform provides direct access to real-time incident, event, detector, probe, weather, transit, and other data sources including ITS device status.

RITIS platform is utilized to collect travel time and speed estimates. This information is collected by third parties such as HERE and Inrix. HERE and Inrix use the information of their users (e.g., travel time and speed) to estimate traffic conditions and identify hot-spots in the network. It is noteworthy that HERE and Inrix use conventional Traffic Message Channels (road segments) to map their data to present meaningful information to end-users (e.g., travelers and operators). Most of these Traffic Message Channels do not lie between two adjacent intersections. Figure 3-5 visualizes this mismatching between desirable “intersection-intersection” and conventional TMC channels for a corridor in a study network. This makes an analysis of HERE and Inrix data more challenging. Another challenge lies in the fact that RITIS data are available in the form of historical reports. Although a user has great flexibility in customizing the content of the report, the required data is obtained with a certain delay and without a form that allows downloaded data to be presented in a straightforward way within MET. This will be more discussed in Section 4.

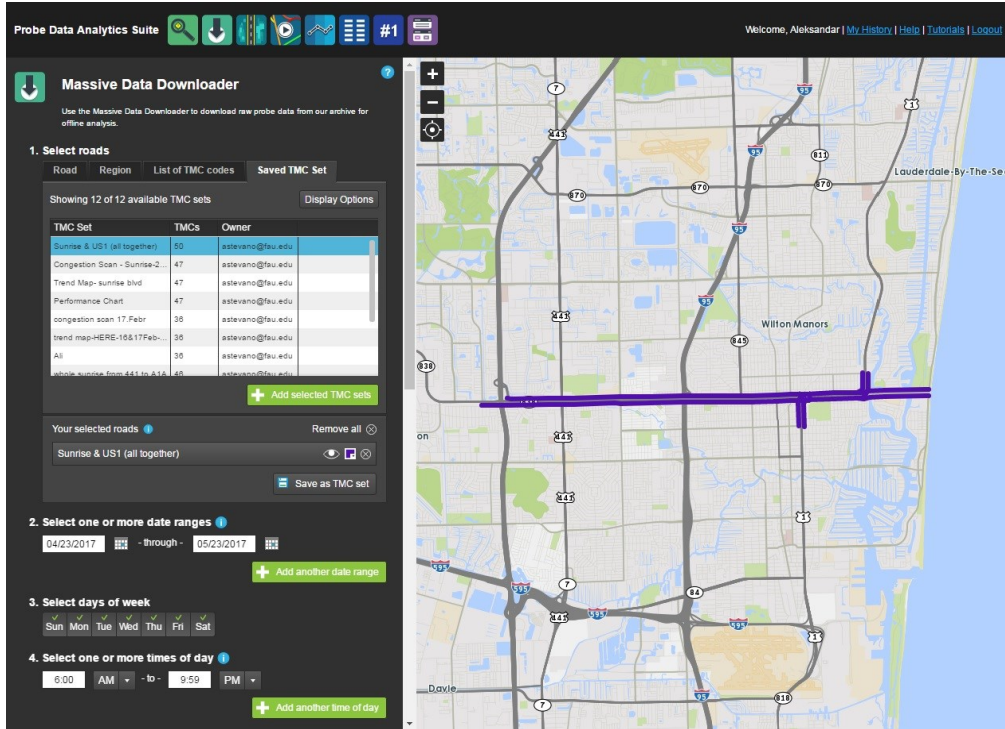


Figure 3-4: RITIS Probe Data Analytics Suite Interface⁴

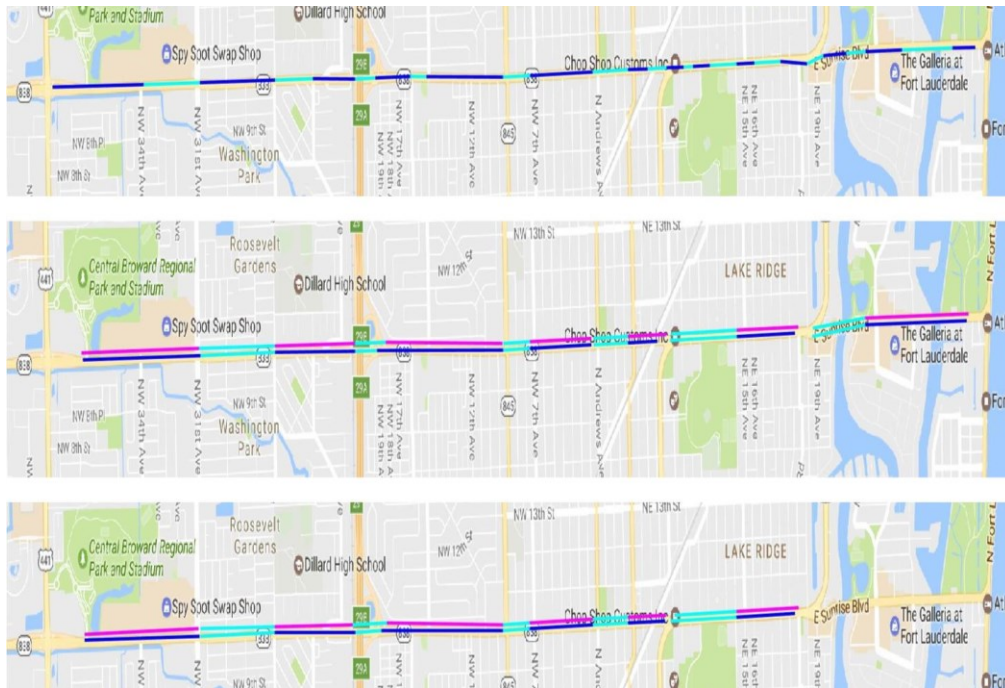


Figure 3-5: Travel Time Segments: Node-To-Node (top), HERE (middle), INRIX (bottom).

⁴ www.ritis.org

3.2.4 Florida Traffic Online – Annual Average Daily Traffic

In addition to MVDS technology, information about the volume may be found at the FDOT Florida Traffic Online website. Florida Traffic Online is a web-based mapping application which provides historical traffic information about daily traffic. The portable and fixed traffic counters are distributed throughout the network in a way to provide high coverage for any portion of the test network. However, the main drawback of this data source is its inability to provide real-time information. Figure 3-6 shows the interface of the Florida Traffic Online website. The location of each data collection site is shown as a green square on the website map. After clicking on each sensor station, the additional information appears as shown in **Error! Reference source not found.** (bottom right).

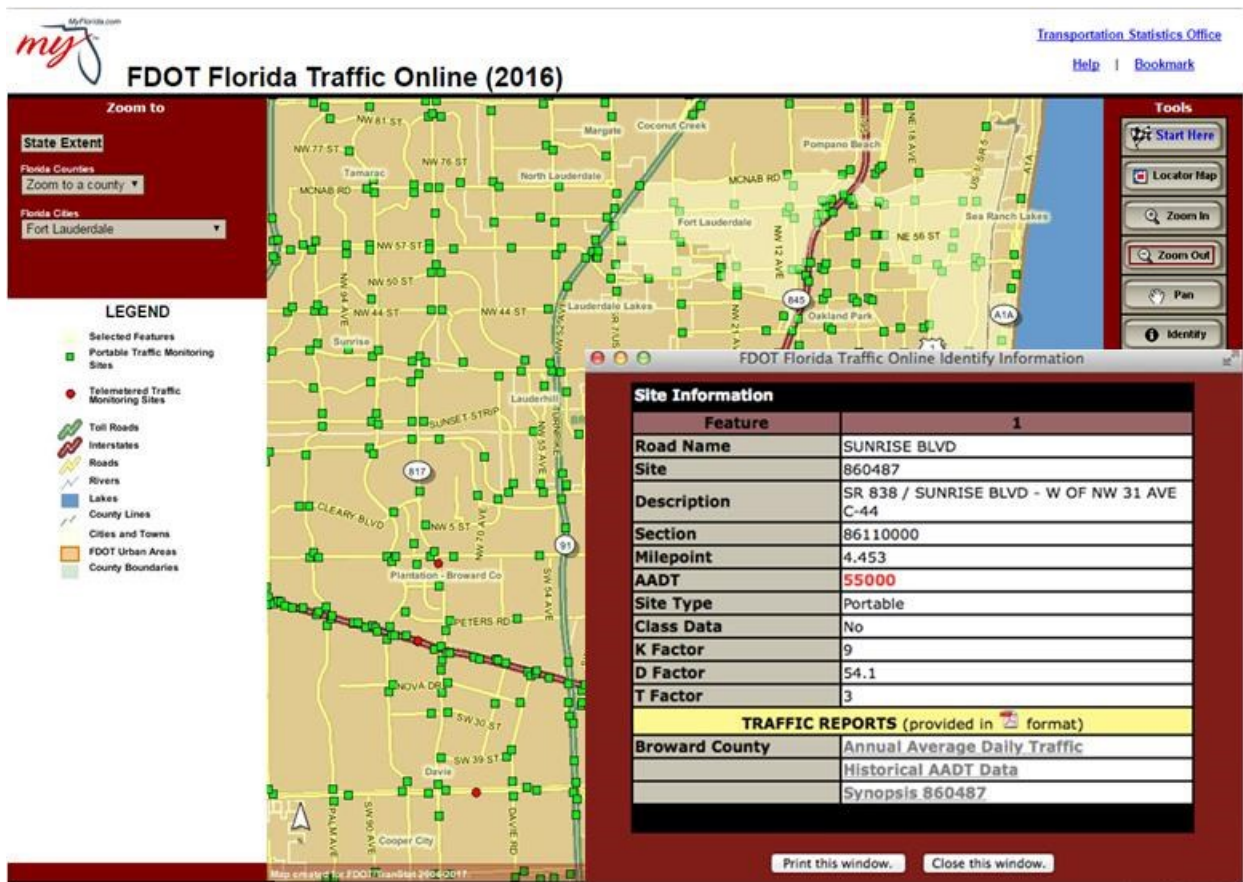


Figure 3-6: FDOT Florida Traffic Online Website Interface⁵

3.2.5 Closed-Circuit Television (CCTV) cameras

Closed-Circuit Television (CCTV) cameras are mounted on traffic light poles and used to provide real-time video streaming of the traffic at the arterial intersections and highway segments.

⁵ <http://flto.dot.state.fl.us/website/FloridaTrafficOnline/viewer.html>

Operators often monitor video streaming and use CCTV cameras to detect traffic congestion and incidental situations in the network. CCTV cameras can be easily rotated to record traffic conditions at different directions. CCTV cameras are deployed along I-95, I-595, I-75, and major arterials in the network. Figure 3-7 shows the location of CCTV cameras (see black markers) on the major arterials and provides a screenshot of two CCTV cameras located in a corridor in the study network. CCTV cameras will be utilized to extract relevant intersection-based performance measures (PM).

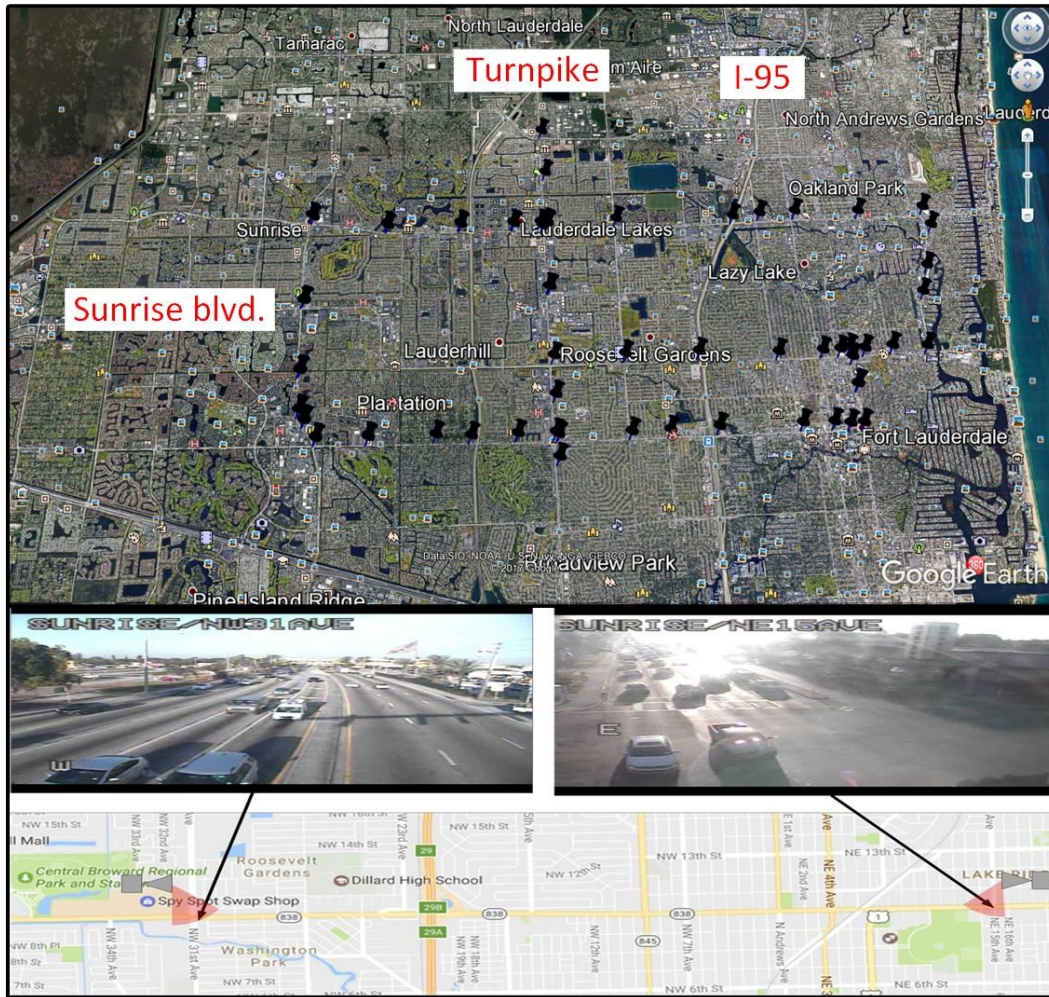


Figure 3-7: Locations in Study Network Covered by CCTV

3.2.6 ATMS.now data

The ATMS.now platform provides signal-related data given in the form of split history and field alarm reports. The split history enables the operator to get information about active patterns, cycle length, and the duration of every signal phase at the intersection of interest. Figure 3-8 shows one instance of the split history report. By using this report, it is possible to compute the performance measures such as average green time and green-to-cycle ratio. In addition, the Split History Report

contains the information required to perform a comparison between programmed and actual green times. Similarly, field alarm reports provide information about the preemption (de)activations. Preemption calls can be requested by emergency vehicles, trains (railroad preemption), boats (drawbridge preemption), or by maintenance crews when doing periodic maintenance and inspection of railroad crossings. ATMS.now data are available for a period of two years (March 2015- March 2017) for most of the intersections along the Sunrise Blvd. These historical ATMS data provide insight into temporal patterns of preemption calls and can help in estimating the impact of preemption on vehicular traffic.

Split History		6/6/2016																
ID: 101																		
Name: PALMETTO PARK ROAD & NW 9 AVE (CMU)																		
Begin Date/Time: 04/23/2016 12:00 AM		End Date/Time: 04/30/2016 11:59 PM																
DateTime	Pattern	Cycle	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10	SP11	SP12	SP13	SP14	SP15	SP16
4/23/2016 00:00:00 AM	48	58	14	24	0	20	0	38	0	20	0	0	0	0	0	0	0	0
4/23/2016 00:01:00 AM	48	39	13	26	0	0	0	39	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:02:00 AM	48	38	13	25	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:02:00 AM	48	37	13	24	0	0	0	37	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:03:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:04:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:04:00 AM	48	26	12	14	0	0	13	13	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:05:00 AM	48	44	1	23	0	20	0	24	0	20	0	0	0	0	0	0	0	0
4/23/2016 00:05:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:06:00 AM	48	40	14	26	0	0	0	40	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:07:00 AM	48	39	14	25	0	0	0	39	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:07:00 AM	48	38	13	25	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:08:00 AM	48	38	13	25	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:09:00 AM	48	38	13	25	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:09:00 AM	48	42	14	28	0	0	0	42	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:10:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:11:00 AM	48	38	13	25	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:11:00 AM	48	39	13	26	0	0	0	39	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:12:00 AM	48	37	13	24	0	0	0	37	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:12:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:13:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:14:00 AM	48	58	13	25	0	20	0	38	0	20	0	0	0	0	0	0	0	0
4/23/2016 00:15:00 AM	48	38	13	25	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:15:00 AM	48	37	13	24	0	0	0	37	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:16:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0
4/23/2016 00:17:00 AM	48	38	14	24	0	0	0	38	0	0	0	0	0	0	0	0	0	0

Figure 3-8: Split History Report

3.3 Available traffic data for arterial and highway segments

Table 3-2 lists the major arterials and freeway segments in the network and provides the data availability for each of them. The first column lists (the grouped) segments in the network while the other columns refer to available platforms for data collection (e.g., MVDS). Table 3-2 shows that some of the road segments contain significant traffic data that come from multiple sources (explained in Section 1.2 and marked with red color in **Error! Reference source not found.**). On a nother side, certain segments do not have any traffic information (see Table 3-2 and **Error! Reference source not found.** for more details).

Table 3-2: Major Corridors in the Network

Corridor / Segment	Dir.	SunGuide	CCTV	RITIS	ATMS	Third party
Commercial Blvd – <i>No ITS</i> I75 – A1A	EW			X		G
Oakland Park – <i>No ITS</i> I75 – University Drive US1 – A1A	EW	MVDS, BT	X	X		G
Oakland Park – <i>With ITS</i> University Drive – US1	EW			X		G
Sunrise Blvd – <i>No ITS</i> I75 - SR7 US1 - A1A	EW			X		G
Sunrise Blvd – <i>With ITS</i> SR7 – US1	EW	MVDS, BT	X	X	X	G
Broward Blvd – <i>No ITS</i> I75 – University Drive US1 – A1A	EW			X		
Broward Blvd – <i>With ITS</i> (University Drive – US1)	EW	MVDS, BT	X	X		G
Davie Blvd – <i>No ITS</i> (University Drive – US1)	EW			X		
Marine Mile Blvd. – <i>No ITS</i> I595 – US1	EW			X		
I595 – <i>With ITS</i> I75 – McIntosh Rd	EW	MVDS, BT	X	X		G
Griffin Rd. – <i>No ITS</i> I75 – US1	EW			X		
I 75 – <i>With ITS</i> Comm. Blvd – Griffin Rd.	NS	MVDS, BT	X	X		G
Flamingo Rd. – <i>No ITS</i> Oakland Blvd – Griffin Rd.	NS			X		

N Nob Hill Rd. – <i>No ITS</i> Commercial Blvd – Griffin Rd.	NS			X		
N Pine Island – <i>No ITS</i> Commercial Blvd – Griffin Rd	NS			X		
University Drive – <i>No ITS</i> Commercial Blvd – Oakland Pk	NS			X		
University Drive – <i>With ITS</i> Oakland Park – Griffin Road	NS	MVDS, BT	X	X		G
Florida Turnpike – <i>With ITS</i> Commercial Blvd – Griffin Rd	NS		X	X		G
SR7 – <i>With ITS</i> Commercial Blvd – Griffin Rd	NS	MVDS, BT	X	X		G
I95 – <i>With ITS</i> Commercial Blvd – Griffin Rd	NS	MVDS, BT	X	X		G
Andrews Avenue – <i>No ITS</i> Commercial Blvd – Griffin Rd	NS					
NE 4 th Avenue – <i>No ITS</i> Commercial Blvd – A1A	NS					
US1 – <i>With ITS</i> Commercial Blvd – Oakland Pk Broward Blvd. – Griffin Rd	NS	MVDS, BT	X	X		G
US1 – <i>No ITS</i> Commercial Blvd – Oakland Pk Broward Blvd. – Griffin Rd	NS					
A1A – <i>No ITS</i> Commercial Blvd – Griffin Rd	NS					

X – Exist EW – East-West; NS-North-South; BT – BlueTOAD; G – Google;

3.4 Performance Measures

A set of methods and analytical procedures was developed and used to process, analyze, and retrieve performance measures from the MET. Such performance measures mostly rely on existing data sources from field devices and third party data providers, such as Inrix, HERE, Waze, and unconventional, emerging data streams, such as data from the existing traffic signal systems, high-resolution data from signal controllers, offline data from drawbridge operations, railroad preemptions, CCTV data feeds, etc. At a minimum, the methods to be developed and integrated into the MET for this task should help Traffic Management Center (TMC) operators and TSM&O Staff to:

- Alert TMC Operators of changes in performance using third party data for parts of the TSM&O-managed network that does not have field equipment (see Section 3.4.1 – 3.4.4). Performance thresholds for changes in performance are defined for recurring and non-recurring events. The method developed for MET allow to sense a change and alert operators if the change reported from third party data is unusual, indicating a non-recurring issue. The method will consider the use of existing mapping platforms already accessible to TMCs such as RITIS, SunGuide and legally available for use for video analytic type solutions. The method will also consider non map based analytic methods. The alert format will be determined based on TMC operator input.
- Apply the methods defined for 3rd party data to places where data collection field equipment is available; such as MVDS and Bluetooth travel time collection systems (see Section 3.4.1 – 3.4.4). In those cases, the methods will be improved upon as the quality and availability of this data is expected to be better and more flexible.
- Report the impacts of railroad pre-emption and moveable bridge pre-emption (see Section 3.4.4). The MET will allow for TSM&O staff to visualize the locations, frequency, and impacts of these events and analyze the benefits of any traffic mitigating efforts. Depending on the maturity and availability of all data, this will be developed for real time use. However, as a minimum this will be provided for post-event analysis and recommendations for improving the real-time applications will be made.
- Perform short-term and long-term trend analysis capabilities of the selected performance measures, estimation of impacts of various recurring and nonrecurring traffic events, and others.
- Assess the node-, link- and network-level performance (see Section 3.4.1 – 3.4.3) in the context of a percent of congested links, network-wide delays, stops, cost of delay to travelers, etc.

Figure 3-9 shows an illustrative example that is used in describing and visualizing some of the PMs that will be presented on the map. Figure 3-9 shows the projected hourly volume (based on observed 15-min volumes at time t_i) on a particular day d^6 (e.g., Wednesday) in 2016. The

⁶ Or group of days (e.g., Tuesday, Wednesday, Thursday) that will be combined.

presented data is recorded at MVDS station j for eastbound direction. The recorded volume data $V_{h,i,j}^d$ is represented in the form of commonly used box-plot⁷. The subscript h refers to historical data. Orange and green dots show the hypothetical 15-min and projected (hourly) volumes, respectively, recorded from 8:45-9:00AM of corresponding day (e.g. Wednesday).

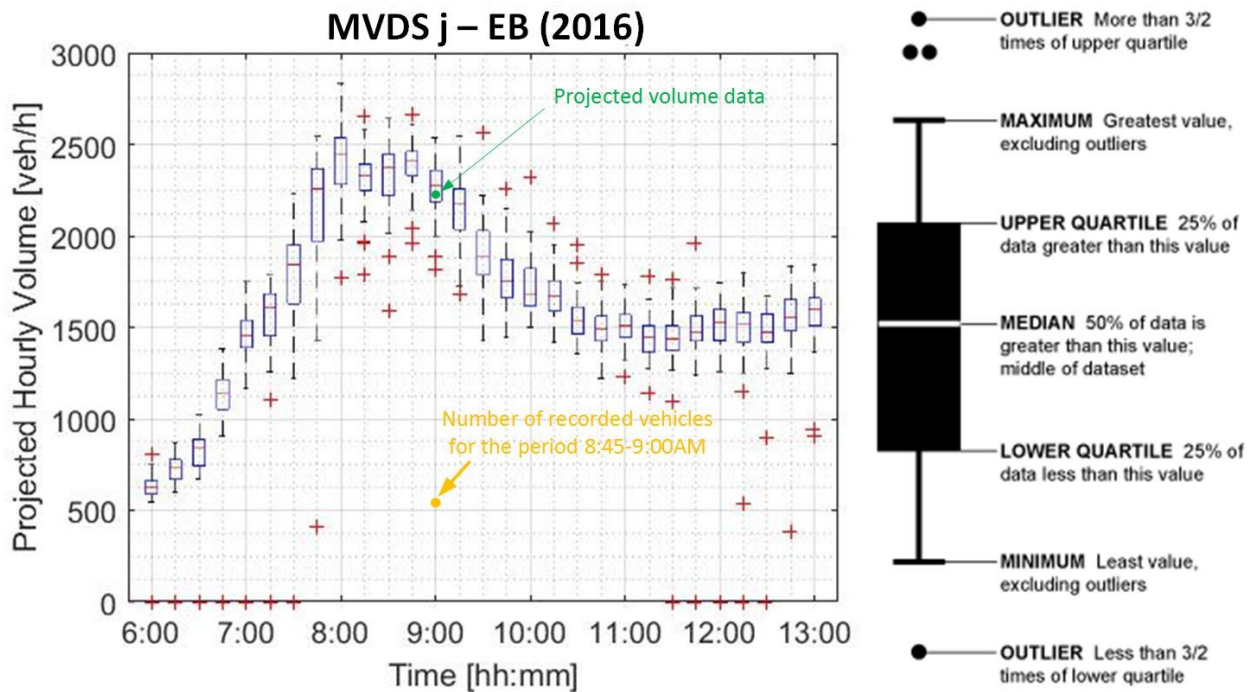


Figure 3-9: An Illustrative Example Used in Explanation of Performance Measures⁸

For simplicity reasons, the performance measures (PMs) are divided into five customized groups, which are explained below:

3.4.1 Fundamental Performance Measures

Fundamental Performance Measures (FPMs) are characterized as those PMs whose processing is not necessary, but they are presented within the MET in their original, unaltered form as retrieved from the third party applications or data sources. Such PMs are those available from SunGuide. One-directional MVDS volume (the center of the orange dot in Figure 3-10 **Error! Reference source not found.**), speed, and occupancy data at single stations (see Figure 3-10)) are representative PMs of this group. These PMs can be easily represented on the map and combined with similar PMs from other sources (e.g., segment travel time). In this way, the available traffic information from multiple sources can be combined on a single map. Table 3-3 lists the performance measures and shows the used sources and updating frequency for each of these PMs. It also shows where the particular PM will be represented.

⁷ <https://flowingdata.com/2008/02/15/how-to-read-and-use-a-box-and-whisker-plot/>

⁸ How to read box-plot - <https://flowingdata.com/2008/02/15/how-to-read-and-use-a-box-and-whisker-plot/>

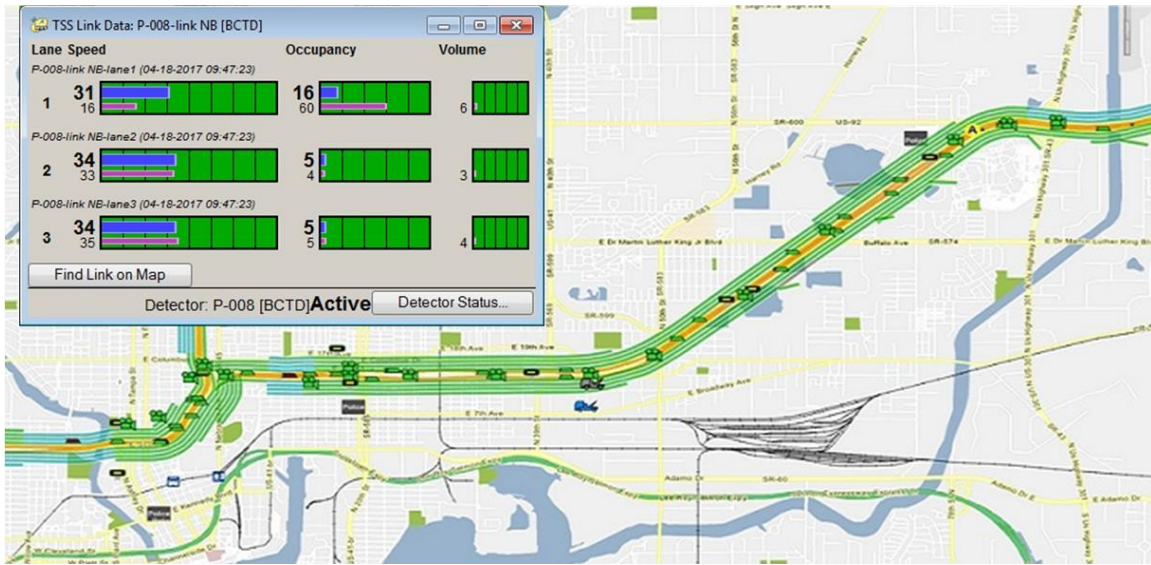


Figure 3-10: An Instance of the Fundamental Performance Measure⁹

Table 3-3: Fundamental Performance Measures

Traffic Parameter	Source	Real Time / Historical	Frequency	Freeway	Arterial
Volume	SunGuide	Real Time	1 min	P	P
Occupancy	SunGuide	Real Time	1 min	P	P
Travel time	RITIS	Historical	15min	S	S
(Current) Speed	RITIS	Historical	15 min	S	S

P – point (MVDS station) S – Segment

3.4.2 Peak, Hourly & 15-min Equivalents of the Fundamental Performance Measures

Peak, hourly, and 15-min equivalents of the Fundamental Performance Measures represent the temporal aggregation of the performance measures defined in Section 3.4.1. In this way, the fundamental performance measures will be delivered to operators in more intuitive and easy-to-understand way. A representative PM of this group is one-directional average peak volume for a particular MVDS station (the center of green dot in **Error! Reference source not found.**). Table

⁹ <http://lucentgp.com/?portfolio=florida-sunguide-software-support-maintenance-and-development>

3-4 lists the performance measures and presents the required computations. It also shows the used data sources and updating frequency for each of these PMs.

Table 3-4: Hourly Equivalent of Fundamental Performance Measures

Performance Measure	Source	Real Time Historical	Updating Frequency	Aggregation Interval [min]	Freeway	Arterial
Average Vol.	SunGuide	Real Time	1 min	15, 60, 120	P	P
Average Occ.	SunGuide	Real Time	1 min	15, 60, 120	P	P
Peak-Hour TT	RITIS	Historical	15 min	60	S	S
Peak-Period TT	RITIS	Historical	15 min	120	S	S
Average Speed	RITIS	Real Time	1 min	15, 60, 120	S	S

P – point (MVDS station) S – Segment

3.4.3 Statistics for Fundamental Performance Measures

These PMs refer to key statistics for performance measures derived in 3.4.1 and 3.4.2. A representative of these PMs is the ratio of current (center of the green dots on **Error! Reference source not found.** and **Error! Reference source not found.**) to historical volume for the corresponding time instance (red line on **Error! Reference source not found.** and **Error! Reference source not found.**). In general, these performance measures (defined in Section 3.4.3) can help operators to assess how the current traffic conditions (described using the PMs in Sections 3.4.1 and 3.4.2) match the expected or historical traffic performance measures at a particular location and time. Unlike the “absolute” PMs defined in Sections 3.4.1 and 3.4.2, the PMs in Section 3.4.3 describe certain statistics (e.g., probabilities, distribution, ratios, clustering) that estimate the compliance of the current and representative (or benchmark) traffic conditions. Table 3-5 lists the performance measures in this group and provide the required computations as well as used data sources.

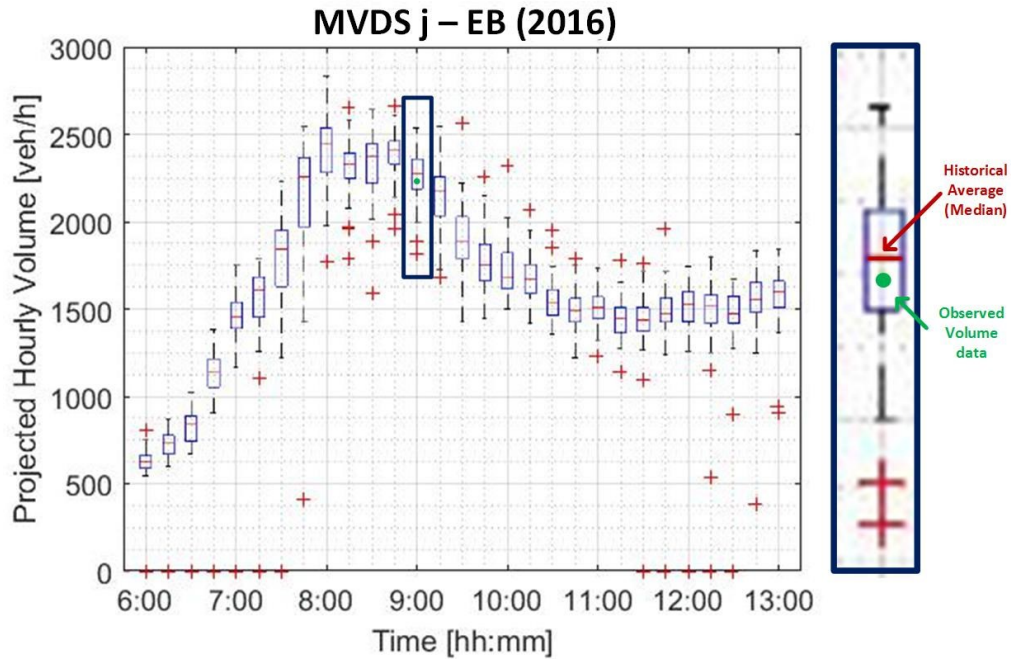


Figure 3-11: Historical Average, Current Volume for a given 15-min Interval

Table 3-5: Statistics for Fundamental Performance Measures

<p>PM: Historical Volume Ratio (HVR)</p> <p>Derivation Method:</p> <p><i>Formula:</i> $HVR = V_{i,j} / V_{h_{i,j}}^d$</p> <p>$V_{h_{i,j}}^d$ – historical volume at time instant i and day d at the MVDS station j</p> <p><i>Description:</i> This PM compares the observed and expected volume. It quantifies deviations of the current from the historical average volume at a particular MVDS station. The historical average is computed based on one year of past volume data.</p> <p><i>Expected Values:</i> 1 +/- 15% (in the described example it would be slightly less than 1)</p>					
Sources	RT	Hist	Frequency	Freeway	Arterial
MVDS	Volume (V_{ij})	Volume ($V_{h_{i,j}}^d$)	$V_{ij} - 1$ min $V_{h_{i,j}}^d - 15$ min	P	P

PM: Travel Time Index (TTI)

*Definition*¹⁰: TTI is the ratio of peak-period travel time ($TT_{i,j}^d$; $i \in (6 - 9AM \cup 4 - 7PM)$) to free-flow travel time ($TT_{ff,j}$) along segment j.

Derivation Method:

Formula: $TTI_{ij} = TT_{i,j}^d / TT_{ff,j}$;

Expected Values: 1.6 +/- 0.5

Sources	RT	Hist	Frequency	Freeway	Arterial
RITIS	Travel Time $TT_{i,j}^d$	Travel Time $TT_{ff,j}$	$TT_{i,j}^d$ - 1 min $TT_{ff,j}^h$ - 15 min	S, C	S, C

PM: Historical Travel Time Ratio (HTTR)

Derivation Method:

Formula: $HTTR = TT_{i,j}^d / TT_{h,i,j}^d$;

$TT_{h,i,j}^d$ – historical travel time at time instant i along the segment j

Description: This PM compares the observed and expected travel times. It quantifies deviations of the current from the historical travel time along a particular segment.

Expected Values: 1 +/- 15%

Sources	RT	Hist	Frequency	Freeway	Arterial
RITIS	Travel Time ($TT_{i,j}^d$)	Travel Time ($TT_{h,i,j}^d$)	$TT_{i,j}^d$ - 1 min $TT_{h,i,j}^d$ - 15 min	S, C	S, C

¹⁰ https://ops.fhwa.dot.gov/perf_measurement/ucr/documentation.htm

PM: The cumulative Volume Distribution function¹¹

Description: This PM describes how the current volume aligns with the historically observed volume, observed at the same MVDS station and during the same period.

Derivation Method: All volumes ($V_{i,j}^d$) at time - i , day - d at station- j will be taken into account to construct the cumulative volume distribution function. $F(v_{i,j}^d)$ shows the probability of having of the volume that is less or equal to $v_{i,j}^d$ where $v_{i,j}^d$ is the reported (or most recent) volume.

Formula: $F(v_{i,j}^d) = P(V_{i,j}^d \leq v_{i,j}^d \mid t = t_i \text{ and } s = s_j)$

Expected Values: 0.5+/- 0.3 (in the described example it would be slightly less than 0.5)

Sources	RT	Hist	Frequency	Freeway	Arterial
MVDS	Volume ($v_{i,j}^d$)	Volume ($V_{i,j}^d$)	$v_{i,j}^d - 1 \text{ min}$ $V_{i,j}^d - 15 \text{ min}$	P	P

PM: The cumulative Travel Time Distribution function⁹

Description: This PM describes how the current TT aligns with the historically observed TT for the same time instance and segment.

Derivation Method: All travel times ($TT_{i,j}^d$) at time the - i , day - d along segment- j will be used to construct the cumulative travel time distribution function. This distribution function will be used to compute $F(tt_{i,j}^d)$ where $F(tt_{i,j}^d)$, shows the probability of having of travel time less than or equal to $tt_{i,j}^d$; $tt_{i,j}^d$ is the observed (or current) travel time.

Formula: $F(tt_{i,j}^d) = P(TT_{i,j}^d \leq tt_{i,j}^d \mid t = t_i \text{ and } s = s_j)$

Expected Values: 0.5+/- 0.3

Sources	RT	Hist	Frequency	Freeway	Arterial
RITIS	Travel Time ($tt_{i,j}^d$)	Travel Time ($TT_{i,j}^d$)	$tt_{i,j}^d - 1 \text{ min}$ $TT_{i,j}^d - 15 \text{ min}$	S, C	S, C

P – point (MVDS station) S – Segment C – corridor (several adjacent segments)

¹¹ https://en.wikipedia.org/wiki/Cumulative_distribution_function

The following performance measures will rely on the output of k-means clustering analysis, where different thresholds and traffic profiles will be defined. K-means clustering is an unsupervised method that divides a dataset into n mutually exclusive classes (or clusters) that share common characteristics and features. For simplicity reasons, a single station j is taken in consideration, although a similar approach can be applied to multiple MVDS stations along a corridor. As opposite to the example described on Figure 3-12, where only the traffic information at particular time instance i is taken into consideration, here all the volume data collected during any time instance, i are considered. The capacity of the corresponding segment (where MVDS is located) is approximated without any loss of generality. The volume data and corresponding volume-to-capacity ratios are separated into four different groups (or clusters) using the k-means clustering [4-5] method. The underlying assumption is that there are four distinctive patterns (or clusters) in traffic volume [5]. Figure 3-12 shows a volume-to-capacity ratio on the j MVDS station during a particular day and presents a hypothetical set of four thresholds used to define corresponding traffic profiles such as low, moderate, high, and peak. In Figure 3-12, traffic volume at 9 AM (see Figure 3-9 and Figure 3-11 for more details) corresponds with a high traffic profile (or Cluster 3). Alternatively, the associated probabilities of a current volume (recorded in RT) belonging to each of four predefined traffic profiles (based on historical data) can also be provided. In this case, k-means clustering will be replaced with the Fuzzy C-means (FCM) clustering [6]. Table 3-6 lists the clustering-based performance measures and provides the required computations and used sources.

In a similar fashion, k-means (or FCM) clustering can be applied to travel-time data.

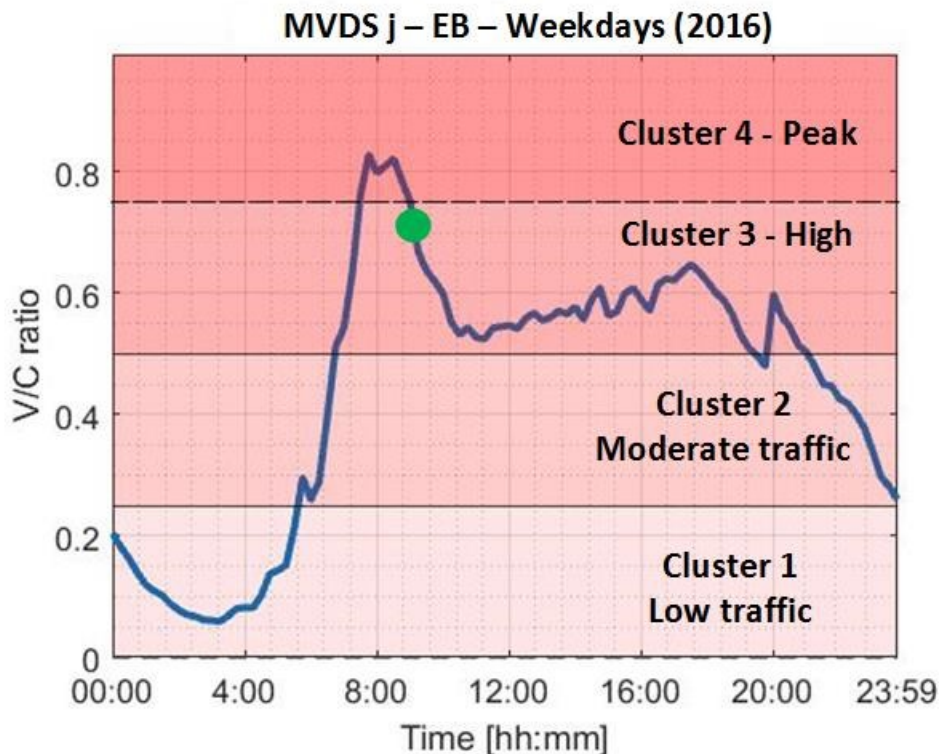


Figure 3-12: Different Traffic Profiles

Table 3-6: *Clustering Performance Measures*

<p>PM: Volume-Based Traffic Profile</p> <p>Description: Descriptive PM that assigns a recorded volume to one traffic profile based on predefined thresholds computed using historical data</p> <p>Derivation Method: Historical volumes at single MVDS stations are used to develop the representative profiles for each cluster. Then, for a current volume obtained in real-time, the method is assigned to one of the four traffic profiles that the observed volume most likely belongs to.</p> <p><i>Output Values:</i> {Light Traffic, Moderate Traffic, High Traffic, Peak Traffic}</p>					
Sources	RT	Hist	Frequency	Freeway	Arterial
MVDS	Volume (V _{ij})	Volume V _{h_{i,j}} ^d & Thresholds	V _{ij} - 1 min V _{h_{i,j}} ^d - 15 min	P - V S,C - V/C	P - V S,C - V/C

<p>PM: Travel Time-Based Traffic Profile</p> <p>Description: Descriptive PM that assigns a recorded travel time (TT) along a segment to one of traffic profiles based on predefined thresholds (computed using historical data for that TT segment)</p> <p>Derivation Method: Travel times along a segment are used to develop the representative profiles for each cluster. Then, current TT is assigned to one of the four traffic profiles.</p> <p><i>Output Values:</i> {Light Traffic, Moderate Traffic, High Traffic, Peak Traffic}</p>					
Sources	RT	Hist	Frequency	Freeway	Arterial
RITIS	(estimated) TT (TT _{ij})	TT _{h_{i,j}} ^d & Thresholds	TT _{ij} - 1 min TT _{h_{i,j}} ^d - 15 min	S, C	S, C

P – point (MVDS station) S – Segment C – corridor (several adjacent segments)

3.4.4 Predicted Performance Measures

Predicted Performance Measures (PPMs) rely on commonly applied machine learning algorithms that fuse data from different sources and provide the performance measures that estimate the

current and future traffic states. For example, short-term (travel time or volume) predictions and estimations of network conditions from information from the small subnetwork are the representative methods of this performance measure. In the case of short-term prediction, current and past traffic data, as well as information about the current time and day, are used to train prediction models for various prediction horizons (e.g., 5 min - 30 min). Commonly used prediction methods (such as moving averages, Support Vector Regression, Pattern Matching, etc.) are evaluated. The best performing method will be deployed within MET. In addition, estimation of the network conditions from partially available real-time data is performed with the help of pattern matching and a significant amount of historical data sets. Table 3-7 lists the performance measures in this group and provides the required computations as well as used data sources.

Table 3-7: Predicted Performance Measures

<p>PM: Volume prediction</p> <p>Description: This PM predicts the volume that might be expected at an MVDS station in next 5-30 minutes (short-term prediction).</p> <p>Derivation Method: For given current and past volume data and corresponding temporal information (e.g., day and hour), the algorithm performs short-term predictions and returns the expected volume for the next 5 to 30 minutes. Various prediction methods ranging from moving averages to Neural Networks and Support Vector Regression will be evaluated, and the best performing method will be deployed.</p> <p><i>Inputs:</i> $V_{ij}, V_{i-5,j}, V_{i-10,j}, t_i, d_i$; V_{ij} – Volume at time i and station j. t – time, d - day</p> <p><i>Output:</i> $V_{i+5,j}, V_{i+10,j}, V_{i+30,j}$</p>					
Sources	RT	Hist	Frequency	Freeway	Arterial
MVDS	V_{ij} ,	$V_{i-5,j}, V_{i-10,j}$.	1 min	S, C	S, C

<p>PM: TT prediction</p> <p>Description: This PM forecasts the travel time for a segment and predefined prediction horizon.</p> <p>Derivation Method: For given, current, and past TT data and information about the current time and day, the algorithm performs short-term predictions and returns the expected travel-time along a segment for a prediction horizon of the next 5 to 30 minutes. Various prediction methods (ranging from moving averages to Neural Networks and Support Vector Regression) will be evaluated, and the best performing method will be deployed.</p>					
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<i>Inputs:</i> $TT_{ij}, TT_{i-5,j}, TT_{i-10,j}, t_i, d_i; TT_{ij}$ – travel time at i along segment j . t – time instant, d - day <i>Output:</i> Predicted Travel Times for 5,10.. 30 min in advance - $TT_{i+5,j}, TT_{i+10,j}, TT_{i+30,j}$					
Sources	RT	Hist	Frequency	Freeway	Arterial
RITIS	TT_{ij} ,	$TT_{i-5,j}, TT_{i-10,j},$	1 min	S, C	S, C

S – Segment C – corridor (several adjacent segments)

3.4.5 Preemption (Rail-road and Draw-bridge) Performance Measures

These performance measures evaluate the impact of railroad preemption and drawbridge operations on vehicular traffic. The average duration of preemption during the peak period and the probability of having the preemption at time t_i are the representative PMs of this group. Table 3-8 shows the full list of performance measures and explains how each of these PM will be derived.

Table 3-8: *Preemption Performance Measures*

PM: Average (historical) duration of preemption calls Description: This PM shows how much time on average the signal was in preemption mode during an observed or current hour due to railroad and drawbridge operations. Derivation Method: Historical information of the preemption calls is used to compute the average duration of railroad and drawbridge preemption for each railroad crossing and drawbridge) in the network and each hour within the day. <i>Example:</i> $rr_{i,j}^h = 120s$ -> average duration of preemption calls on rail-road crossing j and hour i is 120s (or 2 min). <i>Inputs:</i> RR crossing (j) and observed hour (i) <i>Possible Output Value of PM:</i> [0s...3600s]					
Sources	RT	Hist	Frequency	Freeway	Arterial
ATMS	-	Preemption Calls	1hour	-	RR crossing drawbridge

PM: Frequency of preemption calls
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Description: For a given crossing j and 15-min time interval t_i , this PM estimates the expected number of preemption activation within the observed 15-min period, based on historical data.

Derivation Method: Ratio of the total number of preemption calls that occur at a single railroad crossing or drawbridge and at a single period (e.g., 2:45 – 3:00 PM) within a day to the total number of time intervals (e.g., 2:45 – 3:00 PM) within the historical data set.

Formula $pf^h = t_i^p / t_i^t$; t_i^p – total number of preemption calls within a particular i -th 15-min time interval. t_i^t – total number of i -th 15-min time intervals in data set.

Input: railroad crossing or drawbridge and time interval t_i

Possible Output Values: [0,..2]

Sources	RT	Hist	Frequency	Freeway	Arterial
ATMS	-	Preemption Calls	15 min	-	RR crossing drawbridge

PM: Prediction of RR calls and drawbridge openings

Description: Since the ATMS.now data of the preemption call cannot be easily available in real time, the chances of having preemption occurrences at the present time will be estimated using available data sources.

Derivation Method: Historical traffic conditions in the vicinity of railroad crossings will be analyzed in conjunction with the preemption occurrence at the crossing. The available dataset will be classified into two distinctive data sets – one with the activated preemption calls and another without preemption calls within a recorded time interval. The underlying assumption is that traffic conditions at upstream links during the preemption calls are worse than corresponding traffic conditions with no preemption. This assumption can help develop the functional relationship between prevailing traffic conditions and preemption occurrence.

Input Variable: Volume, Occupancy, and TT data in the vicinity of railroad crossings

Possible Outputs: assigned scores - {1 (score > 50%), 0 (score < 50%)}

Sources	RT	Hist	Frequency	Freeway	Arterial
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MVDS, RITIS, ATMS	TT, Volume, Occ, Speed	Preemption Calls	1 min	-	RR crossing drawbridge
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3.4.6 Video analytics-based Performance Measures

Video-based performance measures rely on the outputs obtained through processing the CCTV cameras. These performance measures evaluate the traffic conditions at a particular approach (monitored by CCTV) and estimate the traffic situations at the intersections and corresponding Level of Service (LOS). In particular, the volume, speed, and density are estimated from the CCTV cameras and embedded in a graph. The status of the signal will be either detected from the cameras or inferred from the other known values (e.g., if the volume and speed are estimated as zero and density is high then the signal is most probably red). Presenting multiple traffic parameters (e.g., volume, speed, density) on a single graph time-labeled graph will most likely allow us to identify certain patterns in traffic behavior. These patterns might help us to estimate the level of service (LOS) and might also help traffic operators better understand and visualize the traffic conditions at the approach of the monitored intersections. These video-analytics-based PMs may be good alternatives to some other PMs that rely on high-resolution signal control and detector data. Table 3-9 shows the list of these performance measures and explains their derivation methods.

Table 3-9: *Video Analytics Performance Measures*

PM: Vehicle Counts based on outputs from CCTV					
<i>Description:</i> The proposed method returns the estimated number of cars that enters the intersection from a single approach during the observational period					
<i>Derivation Method:</i> Different object recognition techniques will be evaluated, and the best performing method will be deployed within MET. A significant amount of historical video data will be used for training purposes and to extract the meaningful feature that can help in car detection.					
Sources	RT	Hist	Frequency	Freeway	Arterial
CCTV	-	CCTV video	continuously	-	A

PM: Vehicle Speed (based on outputs from CCTV)					
<i>Description:</i> The proposed method returns the estimated average speed of all cars that enter the intersection from a single approach during an observational period					

Derivation Method: Different object tracking techniques will be evaluated, and the best performing method will be deployed within MET. These techniques try to estimate the amount of time that a vehicle needs to pass a customized segment near the center of an intersection. Historical CCTV data are used for training purposes and extracting meaningful features that can help in estimating the speed of the vehicles.

Sources	RT	Hist	Frequency	Freeway	Arterial
CCTV	-	CCTV video	continuously	-	A

PM: Density (based on outputs from CCTV)

Description: The proposed method returns the estimated density for an intersection approach.

Derivation Method: Density at the time instance t_i is estimated based on the single video frame. The object-recognition technique is used to extract the objects (e.g., cars) within a customized region presented on the single video frame. This customized region refers to a short segment along the intersection approach that will be considered. Different object tracking techniques are evaluated, and the best performing method is deployed within MET. Historical CCTV data is used for training and extracting meaningful features that can help in estimating the speed of the vehicles.

Sources	RT	Hist	Frequency	Freeway	Arterial
CCTV	-	CCTV video	continuously	-	A

PM: Intersection Level of Service (based on inputs CCTV outputs)					
<i>Description:</i> The proposed method returns the estimated LOS for an intersection approach.					
<i>Derivation Method:</i> The relationships and functional dependencies between volume, density, and speed on one side and delay on another side will be inferred using either historical or simulation data. These relationships can vary temporally and spatially. The inferred relationships help in approximating vehicular delay based on traffic counts speed and density, which will also be computed and presented on MET. Level of Service (LOS) is defined based on estimated delay.					
Sources	RT	Hist	Frequency	Freeway	Arterial
CCTV	-	CCTV video	continuously	-	A

PM: Turning Movement Proportion Estimation					
<i>Description:</i> This PM estimates the number of left-, through-, and right-turn vehicles along the single approach at the intersection.					
<i>Derivation Method:</i> Ratio between the estimated number of through-, left-, and right- turning vehicles divided by the total number of vehicles on a particular approach. The number of turning vehicle is estimated as follows:					
<i>Formula:</i> $LT(\%) = LTVeh / TotVe$. LTVeh – number of detected left-turning vehicles that enter the intersection from a particular approach and within the observational period; TotVe – number of detected vehicles that enters the intersection from a particular approach within the observational period.					
Sources	RT	Hist	Frequency	Freeway	Arterial
CCTV	-	CCTV video	continuously	-	A

A – (Intersection) Approach C – corridor (several adjacent segments)

3.4.7 Signal-Based Performance Measures

In addition to the estimation of LOS at the intersection, the additional intersection-based PM will be developed using historical ATMS.now datasets. ATMS.now data contain information about the relevant traffic signal parameters. This information has been widely studied in our previous study, in which we propose advanced dashboards to visualize the data and present them to operators. Similar to this approach, some of the extracted performance measures (within the

dashboard) will be also presented in the MET. Table 3-10 lists some of the relevant intersection-based PM that will be embedded in the MET.

Table 3-10: *Signal Performance Measures*

<p>PM: Phase Duration (based on historical ATMS.now data)</p> <p>Description: This performance measure shows the average historical duration for each phase at an intersection on during an observed or current 15min interval.</p> <p>Derivation Method: Historical ATMS.now data is used to infer average duration of each phase during each 15-min interval within the day. The results will be represented in seconds or as %. The sum of all phase durations will be 900 seconds (i.e., 15 min) or 100%.</p> <p>Formula: $PD_h = \frac{1}{j} \sum_{d=1}^j \sum_{i=1}^n PD_i^d$; where j represents the total number of days with the data set, and n (that is a function of d) is the number of cycles within the observed 15-min interval</p>					
Sources	RT	Hist	Frequency	Freeway	Arterial
ATMS.now	-	Phase Duration	15 min	-	intersection

<p>PM: Green-to-Cycle Ratio</p> <p>Description: this PM shows the ratio of average green time to average cycle time for an observed 15-min period of interest.</p> <p>Derivation Method: the ratio between the average duration of green time (GT) and the average length of the cycles (C) for an observed or current 15-min interval.</p> <p>Formula $GCR(\%) = GT / C$.</p>					
Sources	RT	Hist	Frequency	Freeway	Arterial
ATMS.now	-	Green time, Cycle time	15 min	-	intersection

3.4.8 Summary of the Performance Measures

Table 3-11 provides an overview of the performance measures integrated in the MET. Table 3-11 also lists the methods utilized to compute the performance measures. These performance measures can help traffic operators to better understand short- and long-term changes in traffic (see Table 3-11) as well as to evaluate the benefits (e.g., in terms of travel time savings) of operational strategies

(e.g., signal retiming) through before-after analysis. Noteworthy, some of these performance measures are properly described in the literature and already embedded in the similar traffic platforms. On the other side, some of the performance measures proposed to the MET are introduced in the literature but have not been explicitly deployed in the field. We refer to this as performance measures in the testing or validation phase. Finally, some of the proposed performance measures are still in exploratory or investigating phase, and it is not clear whether these measures will be integrated in the MET tool. Table 3-12 shows the development stages and potential of the performance measures and associated methods proposed within MET.

Table 3-11: Summary of the Performance Measures

Performance Measure (PM)	Applied Methods	Short-term analysis	Long-term analysis
1. Fundamental PM <ul style="list-style-type: none"> • Volume • Occupancy • Travel Time • Current Speed 	None	These PMs, computed in real-time, describe the current traffic conditions and therefore might be the first sign of suspicious / unusual behavior in the network. However, only experienced operators might be able to identify some of these disturbances, due to the “absolute” representation of the provided PMs. To overcome this issue, we introduce key statistics of PM.	These performance measures will be presented over a longer period defined by operators in the form of historical reports. These reports can then help in revealing and better understanding the traffic trends, patterns and certain bottlenecks & conflict points in the network over a pre-defined period.
2. Peak, Hourly, and 15-min Equivalent of Fundamental PM <ul style="list-style-type: none"> • Average Vol. • Average Occ. • Peak-Hour TT • Peak-Period TT • Average Speed 	Basic Aggregation Methods		

Performance Measure (PM)	Applied Methods	Short-term analysis	Long-term analysis
<p>3. Statistics for Fundamental PM</p> <ul style="list-style-type: none"> • Historical Volume Ratio (HVR) • Historical Travel Time Ratio (HTTR) • Travel Time Index (TTI) • Cumulative Volume Distribution Function • Cumulative Travel Time Distribution Function • Volume-Based Traffic Profile • Travel Time-Based Traffic Profile 	<p>Basic statistics:</p> <ul style="list-style-type: none"> - filtering - averaging - probability distribution - k-means clustering 	<p>These PMs are compared with the corresponding historical (hourly) metrics for the same time instance and location. Extreme values (threshold will be defined) can instantly and explicitly suggest certain irregularities (or unusual situations) in the network to operators. Through cross-comparison with other relevant PMs (either within this or another group of PM), operators might be able to reveal major causes for such unusual situations.</p>	<p>Recorded PMs are compared with the corresponding historical and daily metrics for the same location. This comparison is performed for several consecutive days/weeks and given in the form of a report. This analysis should help operators better understand changes in traffic observed over a longer period. A possible outcome of this analysis may show that certain parts of the network are (constantly) more congested than they were earlier (last year, or last month- TBD). This might indicate that certain interventions (i.e., signal retiming) might be considered. Noteworthy, the identified fluctuations in traffic will be separated from the (regular) seasonal fluctuations.</p>
<p>4. Predicted PM</p> <ul style="list-style-type: none"> • Volume Prediction • Travel-Time Prediction 	<p>Commonly applied prediction algorithms:</p> <ul style="list-style-type: none"> - Moving Average - Neural Networks (NN) - Support Vector Regression 	<p>Our underlying assumption (also observed in numerous literature) states that traffic parameters (e.g., volume, travel time) can be quite accurately predicted during off-peak hours and fairly accurately predicted during the distinctive peak hours as well as transition periods. If, however,</p>	<p>If the prediction error is constantly significantly large (the threshold will be investigated), this might indicate that the link or network is exhibiting a certain behavior or pattern that could not be easily observed in the past. By matching this output with the other performance measures, operators can better understand potential causes for such network behavior</p>

		the prediction error is quite high at certain times, this might indicate some unusual behavior at a certain facility (link or subnetwork).	(that results in large(r) prediction error(s).
<p>5. Preemption PM (Rail-road and Draw-bridge)</p> <ul style="list-style-type: none"> • Average (historical) duration of preemption calls • Frequency of preemption calls • Prediction of RR calls and drawbridge openings 	<p>Basic statistics:</p> <ul style="list-style-type: none"> - filtering -averaging - probability distribution 	<p>This PM can help operators estimate whether (and how many) network disturbances, especially near railroad crossings and drawbridges, are caused by preemption operations.</p>	<p>By matching the frequency of preemption calls with the estimated travel-time and volume near railroad crossings and drawbridges, operators might be able to easily quantify the impact of preemption operations on vehicular traffic. Intuitively, this impact is expected to be lower during off-peak hours than during peak periods. This investigation (over a longer period) should reveal some good and bad cases in the context of preemption operations as well as critical situations that will need certain interventions.</p>
<p>6. Video-analytics based PM</p> <ul style="list-style-type: none"> • Vehicle counts • Vehicle speed • Density • Turning Movement Proportion Estim. • Estimation of Level-of-service based on speed, density and vehicle count (flow) 	<p>Artificial Intelligence Method:</p> <p>Convolutional Neural Network has already been applied for the car and object recognition and counting [7], speed estimation [8], etc.</p>	<p>These performance measures should quantify traffic operations near intersections. In addition, these PM should estimate the level of service (LOS), an explicit measure of the quality of traffic at a certain facility. In this way, certain conflict situations near the</p>	<p>These performance measures estimate the LOS for certain movements and identify these movements that exhibit an unacceptable level of service, or LOS F. In other words, these performance measures reveal the facilities where certain interventions should be undertaken (i.e., revision of the existing capacity, signal retiming, etc). In addition, these PMs provide one of the essential inputs for signal</p>

	<p>However, there is still no method that tries to combine the outputs from video processing in order to estimate the level of service at a certain facility</p>	<p>intersections might be revealed.</p> <p>In additions operators will have both qualitative (through video) and quantitative (using performance measures) estimation of traffic conditions within the monitored intersections.</p>	<p>retiming – (estimated) turning movement counts.</p>
Performance Measure (PM)	Applied Methods	Short-term analysis	Long-term analysis
<p>7. Signal based PM</p> <ul style="list-style-type: none"> • Phase Duration • Green-to-Cycle ratio 	<p>Basic Statistics:</p> <ul style="list-style-type: none"> - averaging - filtering 	<p>These performance measures will be based on historical (offline) data, and therefore cannot help operators in the context of real-time operations. However, historical phase duration and green-to-cycle ratios (provided in the form of historical reports) might still be beneficial for understanding certain bottlenecks and conflict situations in a network.</p>	

Table 3-12: Level of Deployment of Performance Measures Within Existing Traffic Tools

Performance Measure	Stage / Maturity / Level of deployment	Potential Extension
<p>1. Fundamental PM</p> <ul style="list-style-type: none"> • Volume • Occupancy • Travel Time • (current) Speed <p>2. Peak, Hourly, and 15-min Equivalents of Fundamental PM</p> <ul style="list-style-type: none"> • Average Vol. • Average Occ. • Peak-Hour TT • Peak-Period TT • Average Speed 	<p>These well-known PMs are properly defined and described in the literature and proved to work well in the field.</p> <p>These PMs are widely deployed within many real-time systems (e.g., SunGuide, RITIS).</p>	<p>There is no room for significant improvement.</p>
<p>3. Statistics for Fundamental PM</p> <ul style="list-style-type: none"> • Historical Volume Ratio (HVR) • Historical Travel Time Ratio (HTTR) • Travel Time Index (TTI) • The cumulative Volume Distribution function • The cumulative Travel Time Distribution function • Volume-Based Traffic Profile • Travel Time-Based Traffic Profile 	<p>All these methods and performance measures have been defined and properly described in the literature. However, only TTI has been explicitly deployed, while other PMs are currently in testing and validation phase.</p>	<p>The PMs that are currently in the testing and validation phase offer a great potential to traffic operators; i.e., they can help traffic operators to better understand compliance of real-time data with the corresponding historical values. In additions, identification of traffic profiles is based on promising k-means clustering technique and used to separate (network, corridor, or link) traffic conditions into distinctive groups (clusters) based on the level of congestion. None of these PMs (except TTI) are explicitly deployed within any of available traffic platforms.</p>
<p>4. Predicted PM</p> <ul style="list-style-type: none"> • Volume Prediction 	<p>Numerous traffic forecasting methods are described and evaluated in the relevant literature. Some</p>	<p>The predicted PMs assess traffic behavior in the near future and, in this way, offer</p>

<ul style="list-style-type: none"> • Travel-Time prediction 	<p>platforms (e.g., Google) deploy certain forecasting algorithms without providing any details on the used technique. We plan to evaluate multiple forecasting techniques for provided multiple & heterogeneous datasets and deploy these methods that provide the best accuracy for tested datasets. Due to uncertainties of the method and associated parameters, we assign these PMs to the testing and validation phase.</p>	<p>a great potential for traffic operators. These PMs are often seen as key and often unrevealed components of similar mapping platforms (e.g., Google)</p>
<p>5. Preemption PM (railroad and drawbridge)</p> <ul style="list-style-type: none"> • Average (historical) duration of preemption calls • Frequency of preemption calls • Prediction of railroad calls and drawbridge openings 	<p>Historical-preemption-based PMs related to duration and frequency of recorded preemption calls can be easily extracted using available methods from the literature. We assign this group of PMS to the testing/validation phase since they are most likely be implemented in the MET tool.</p> <p>The relevant literature also describes how to quantify the impact of preemption operations on vehicular traffic. We plan to use the available methods and data from multiple heterogeneous sources (i.e., information about preemption requests and RITIS travel-time data) in order to quantify this impact. Since (i) the used data sources are still not completely defined, and (ii) the correlations among the data that come from different sources is not proven, we assign this analysis to an exploratory phase.</p> <p>Noteworthy, a new set of PMs will be proposed to properly describe the impact of preemption operations on vehicular traffic. None of the preemption-based performance</p>	<p>Preemption-based-performance measures have not been investigated by other relevant mapping tool, although they offer great potential for understanding certain disturbances in traffic behavior (especially at nearby road segments). The literature describes the certain methods that can be used to assess the impact of preemption on vehicular traffic. However, these methods have not been explicitly validated (and deployed in the field) in the context of railroad and drawbridge preemption operations.</p>

	measures are currently present within similar traffic platforms.	
<p>6. Video-analytics-based PM</p> <ul style="list-style-type: none"> • Vehicle Counts • Vehicle Speed • Density • Estimated Turning Movement Proportion • Estimation of LOS based on speed, density and vehicle count (flow) 	<p>Video-based analytics have received great attention in recent years, due to rapid development in sensor technology and numerous advanced algorithms that are proposed in the field of video and image processing. Certain methods have been proposed to (i) count the objects (from video images and frames), (ii) assess the speed of the objects from video data, and (iii) count the number of objects on a single frame (density). We assign the associated PMs to testing/validation phase since the significant research has been performed in this direction.</p> <p>On the other side, there is no explicit procedure in the literature that describes how to estimate LOS of an observed approach from video data. For this reason, we assign the stage of these LOS-related performance measures (extracted from video data) to the exploratory or investigating phase.</p>	<p>Video analytics offer a great potential for traffic applications. In terms of field deployment, these applications remain limited to access of a live feed (e.g., real-time video stream). Video based analytics provide promising alternatives to common data collection methods and can assess the fundamental traffic parameters (flow, speed, and density). We will explore whether and how video analytics can be used to assess the quality of traffic (by examining LOS) at certain intersections.</p>
<p>7. Signal-based PM</p> <ul style="list-style-type: none"> • Phase Duration • Green-to-Cycle ratio 	<p>The signal-based performance measure will be derived from historical data. The applied methods are already developed and proven to work in our other relevant projects.</p> <p>So far, signal-based performance measures are not embedded in any existing traffic platform.</p>	<p>The signal-based performance measures, derived in real-time, offer great potential. However, the signal data are often not easily available in real-time, and this is often seen as a key limitation and bottleneck in generating signal-related performance measures.</p>

3.5 Temporal and Spatial Aggregation of Traffic Data and Performance Measures

In the context of temporal data representation, the proposed MET can present three groups of data:

- (i) Performance measures (presented in Section 3.4) that refer to the *present* and involve at least one real-time data source
- (ii) Historical data will be reported through either some of the performance measures that consider only historical datasets (e.g., ATMS.now) or through user-generated reports that refer to the *past* and do not require any real-time data source
- (iii) *Future* data will be assessed with the help of predictive analytics (see Section 3.4.4)

Hence, the performance measures will be visualized on the map and reported in historical reports for further offline analysis. The MET will be able to generate the daily, weekly, and monthly reports that can help traffic operators better understand traffic performance over a longer period.

Figure 3-13 shows the potential visual representation of performance measures (described in Section 3.4) in historical reports. In the context of fundamental performance measures, the daily traffic (recorded in RT) will be presented along with the representative historical values (e.g., minimums, maximums, and averages) for the same location and day (see

Figure 3-13 top).

In the context of spatial data representation, performance measure will be reported on a node, approach, link corridor, and network level. Table 3-13 lists the examples for each spatial level. While the node, approach, and link level are quite common in the relevant literature, the corridor and network level cannot be seen on a similar tool. The corridor and network performance measures can help operators better understand the quality of traffic on a particular corridor or subnetwork. A limited number of predefined corridors and (sub)networks (based on feedback from operators) will be available through MET. The performance of these predefined subnetworks will be presented in real-time on the map or in the form of historical reports.

Table 3-13: *Spatial Data Representation*

Spatial unit	Node (point)	Approach	Link (segment)	Corridor (set of adjacent links)	(sub) Network
PM	MVDS volume	Video-analytics-based PM	HERE travel time	Level of congestion	(sub)Network delay

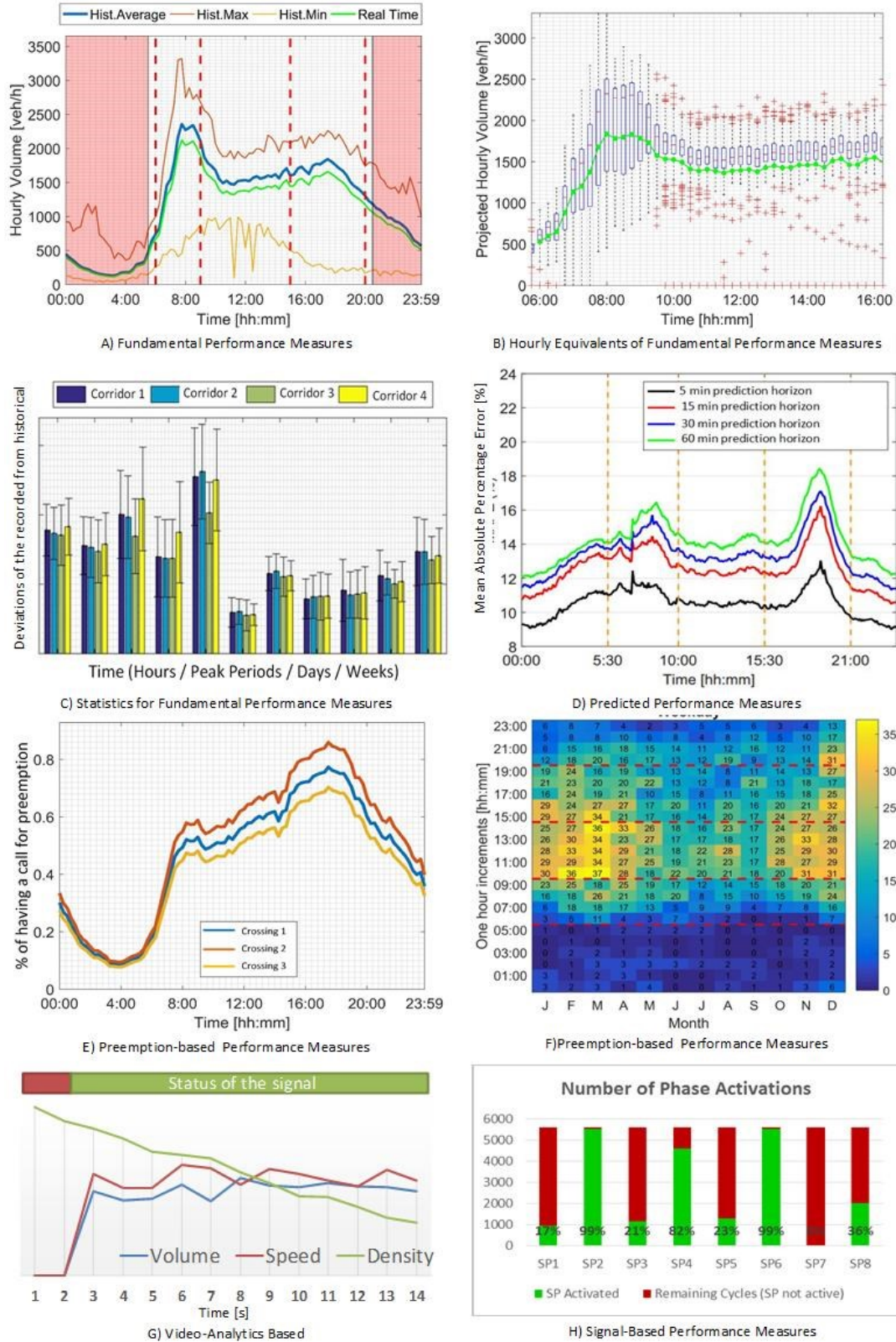


Figure 3-13: Graphical Visualization of Performance Measures in Historical Reports

4. SCOPE AND FUNCTIONAL SPECIFICATIONS OF THE MAP EVALUATION TOOL

This chapter covers the geographical scope and data sources for the deployment of the initial version of Map Evaluation Tool (MET). Then, data-flow within the MET is described, and relevant software and hardware platforms are listed. In the next part, an early layout of the user-interface is presented by listing the functional specifications and options that will be available to a user. Finally, the authors propose some new potential names for the tool.

4.1 Data Sources for the Initial Version of the Map Evaluation Tool

The data collection and analysis, conducted over several months, shows high (temporal and spatial) heterogeneity of the collected data. For the purposes of this project to create the MET, the following data sources will be embedded in the initial version of MET.

4.1.1 Real-time Data Sources

- **Microwave Vehicle Detection System (MVDS).** One directional volume and density data for 50 MVDS stations in the network (see Figure 3.1 and Figure 3.2) will be provided for every minute. These data, recorded per lane at mid block locations, will be reported per each station and direction. Although the (spot) speed data are available for analysis we decided to use HERE travel time data for two following reasons: (i) HERE provides higher spatial network coverage than MVDS data source (i.e., there are thousands of segments in the network for which HERE provides data); and (ii) the reported segment-based speed can reflect the (occasionally congested) traffic conditions in the vicinity of the intersections while this might not be possible using mid-block speed data.
- **HERE Travel-time and Speed Data.** Real-time travel-time and speed data are provided for some of the road segments in Florida with the sampling interval of one minute. This data source may not report information for all segments in the network (presented in Figure 3-1) in a timely manner. In this case, the missing values will be replaced in the historical data records.
- **Incidents and Event Data.** The incident-related data are retrieved from the SunGuide platform and explicitly presented within the MET tool without any significant modification. The incident records for the study area network will be displayed on the map with an update frequency that will depend on the compatibility of SunGuide and the MET platforms.
- **Activation of Drawbridge and Railroad Crossings.** Drawbridge and at-grade railroad crossing delay is to be monitored from the onset of the corresponding gate and traffic signal pre-emption associated with the subject crossing. For railroad-crossings and most of the drawbridge-crossings in the study network, the real-time data will come from the traffic signal system when the traffic signal is pre-empted by the railroad or drawbridge gate and

will be updated every minute. Noteworthy, the reported activation time will be given to the precision of 1 minute (since this information is reported in the format “hh:mm”). For the remaining drawbridges in the network, the historical data will be used to substitute missing real-time data. Table 4-1 lists the drawbridge crossings in the network and data format that will be used for each of these crossings.

Table 4-1: Used Data Formats for Each Drawbridge Crossing in Network

Crossing	Signal ID	Availability of real-time data	Availability of historical data
SE 17 St & SE 23 Ave	2025	No	Yes
Davie Blvd & SW 15 Ave	2105	Yes	Yes
Sunrise Blvd & NE 26 Ave	2126	Yes	Yes
SR A1A & Oakland Park Blvd	1011	No	Yes
Las Olas Blvd & Las Olas Cir	N/A	No	Yes
Commercial Blvd & NE 51 St	N/A	No	Yes

4.1.2 Historical Data

- **Microwave Vehicle Detection System (MVDS) data** from 50 MVDS stations in the network will be collected for the last two years. These one directional volume and density data collected per lane will be aggregated for each direction in 15-minute bins
- **HERE travel-time and speed data** for all road-segments in the network will be collected (from RITIS website) for the period of two years. The data will be aggregated in 15-minute intervals.
- **Activation of drawbridge and railroad crossings** will be extracted from either (i) recordings of preemption activation obtained from the traffic signal system software (ATMS.now) platform or (ii) manuscript of drawbridge logs recorded by operators. The data will be collected for a period of one year and aggregated in 15-minute bins.
- **Annual Average Daily Traffic data (AADT)** for most of the sites in the network will be collected for the last five-10 years (based on availability) and embedded in the MET tool.
- **Signal-related data**, including cycle length and phase duration will be retrieved from split history and preemption reports. These reports will be downloaded from ATMS.now platform. The signal data will be collected for the period of one year (Jan.-Dec. 2017) for ~200 traffic signals installed on major corridors (laying in east-west direction) in the study

area network. Table 4-2 lists these corridors and provides the number of signals along each corridor.

Table 4-2: List of Corridors for Collected Signal Data

Corridor	Number of Traffic Signals
Commercial Blvd. (SR 870)	32
Oakland Park Blvd. (SR 813)	47
Sunrise Blvd. (SR 838)	48
Broward Blvd. (SR 842)	38
Davie (Blvd. SR 736)	15
Griffin Rd. (SR 818)	33

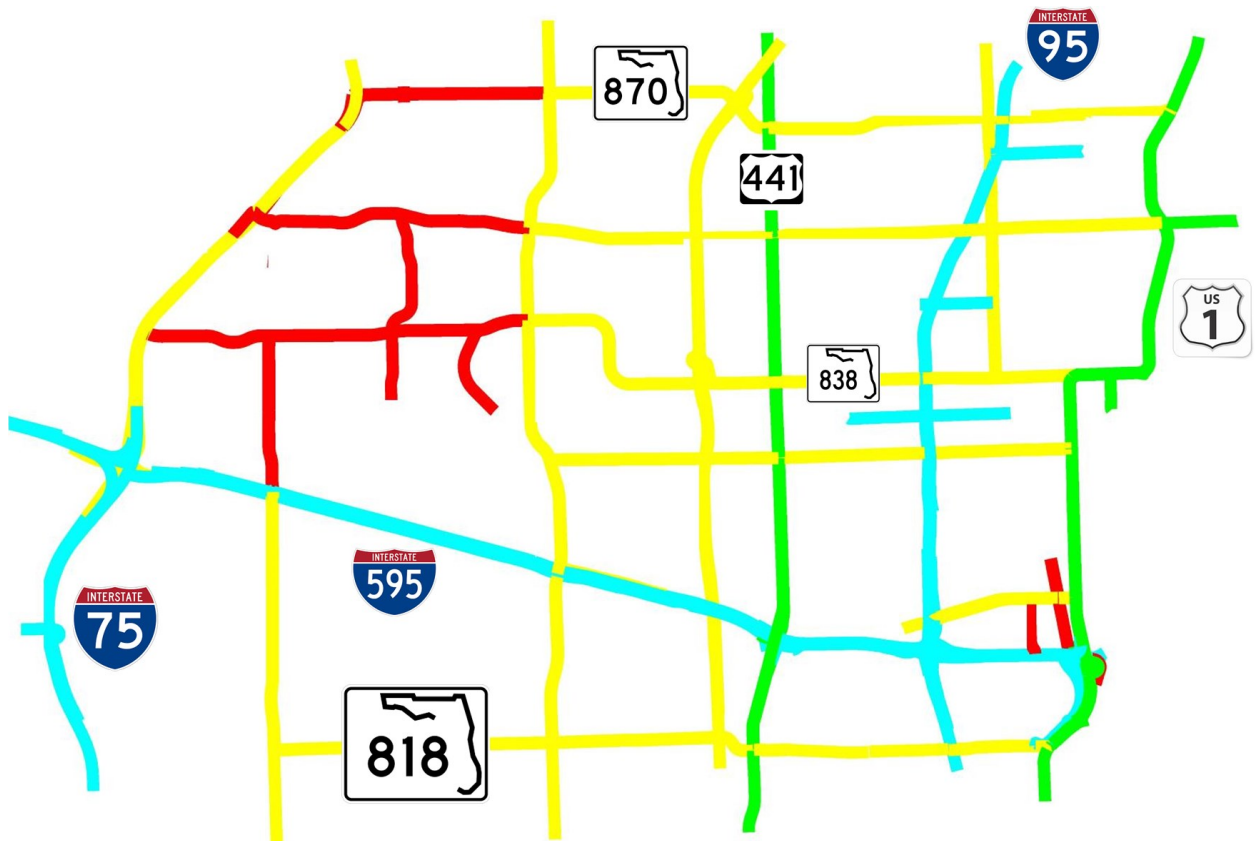
4.2 Geographical Scope for Initial Deployment of the MET

The spatial coverage of traffic data presented in Section 4.1 differs among various data types. While some real-time traffic data may be available even for the parts of the region outside of the predefined study area, some other traffic data may not be available in real-time format, even for the proposed network. The following text briefly explains spatial coverage of each of the available data sets.

The geometry of the segments within the study area network has been provided to FAU research team. These segments and their corresponding latitude and longitude coordinated are provided in the form of shape file. This shapefile contains the relevant information that help us accurately match the available traffic data to it. Figure 4-1 shows a screenshot of the provided shape-file based network where the major freeway and arterial roads are marked.

The study area network, shown in Figure 3-1 and Figure 4-1, contains:

- 120 miles of Interstate freeway, 46.4 miles of Interstate roads and 172.2 miles of State Roads.
- 50 MVDS stations for which FDOT District 4 provided both real-time and historical data.
- Thousands of travel-time segments for which RITIS provided historical travel-time and speed data. However, real-time data from HERE is not available for all of these segments. The missing data will be imputed using a historical average method.
- Approximately 200 traffic signals installed on major (east-west) corridors in the network will be used in the analysis. Only historical data for signal timings of these signals are being provided by Broward County.
- Six drawbridge and 29 railroad crossings presented in the network will be covered. Real-time data is available for all railroad and two drawbridge crossings. Historical data are available for all crossings.
- Numerous sites with permanent and portable tube counts are used to retrieve the data for daily and annual traffic.



Type of Facility	# of links in the network	Total length (mi)	Color on the map
Interstate Freeway (I-95 & I-595 & I-75)	162	120.3	Cyan
Interstate Roads (US-1 & US-441)	125	46.4	Green
State Roads (including Turnpike)	437	172.2	Yellow
Unclassified	103	39.4	Red
All	827	378.3	

Figure 4-1: Layout of the provided (HERE) shapefile

4.3 Data Flow within the Map Evaluation Tool

The traffic data described in Sections 4.1 are 4.2 are collected from diverse sources. More specifically the collected data are provided by:

- **FDOT**; the MVDS and SunGuide system provide volume, occupancy, incident, and event data.
- **Broward County** provides signal-related data from ATMS.now and historical and real-time activation of drawbridge and railroad crossings.

- **HERE** and **RITIS** provide real-time and historical travel-time information, respectively.

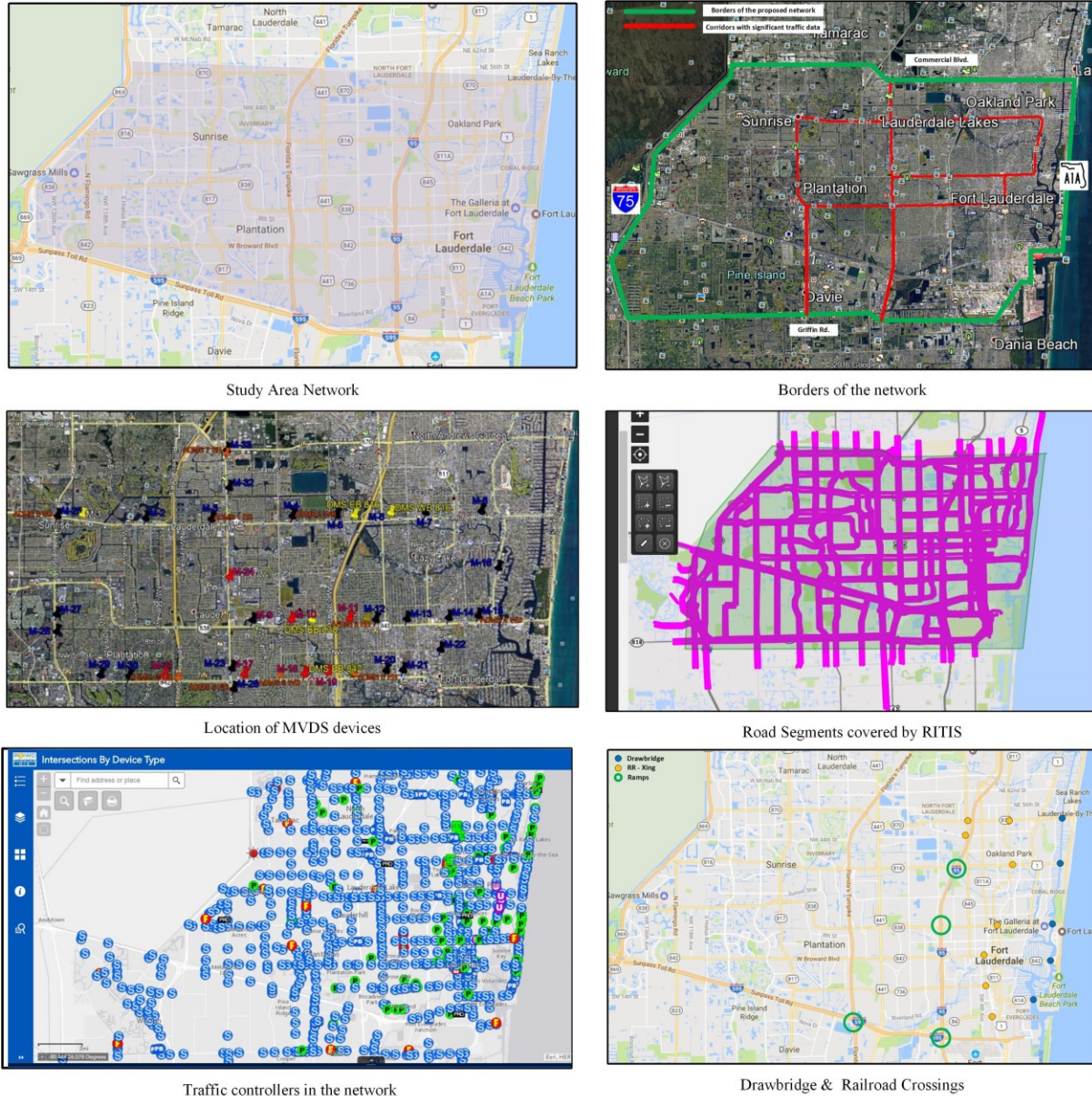


Figure 4-2: Area Network (*top*) and Spatial Coverage of Provided Data Sources (*center & bottom*)

The Map Evaluation Tool provides a consolidated database of raw traffic data collected from various sources. In more technical terms, The MET is a real-time archive data management system that collects, stores, and processes raw data in real time. The MET database will be continuously updated and will be located on the cloud. Numerical methods (described in Section 2) will be applied to the consolidated database to compute the relevant Performance Measures (PMs), described in Section 4.4. This is referred to as a back-end component of the MET development.

Computed performance measures will be delivered to operators with the help of an interactive user-interface (explained in more details in Section 4.4). This is referred to as the front-end component of the development of MET. Hence, once the raw data arrives at MET, the data will be (pre)processed and embedded in the MET database; the updated database will be then used for extraction of performance measures, based on user-defined temporal and/or spatial aggregations (explained in Section 4.4).

The MET will utilize a web-based interface that allows FDOT staff equipped with Internet connection and a standard web browser to access the system. Users will need to make an account before using the system. There will be at least two levels of privilege: (i) *full access* – allowing access to all MET features; (ii) *limited access* –allowing access only to specific performance measures and MET characteristics related to a specific domain (e.g., signal operations).

4.4 Hardware and Software within Map Evaluation Tool

The MET will be hosted on a cloud-computing platform utilizing resources and services of one of the common commercial cloud-computing providers, such as Amazon or Microsoft Azure. The cloud-based MET should be able to efficiently deal with the significant spatial databases and real-time data sources. The MET consists of three main components: (1) real-time data collection, (2) image processing (which will be used for some MET applications), and (3) storage and access for spatial databases. Each of the three components requires a dedicated server to timely process the real-time data sets. The MET will be constructed by using a three-tier architecture based on a Model-Viewer-Controller (MVC) data model¹². MVC is a well-known pattern in software architecture used to decompose the system into smaller modules. Model will create and access the data. View will visualize the dataset. Control connects Model and Viewer and coordinate all business processes. The presentation tier will allow users to request data sets and visualize important information. The data processing tier will provide scalable data-processing algorithms to handle large-size datasets. The third tier will store both historical and real-time data sets into a spatial database system (e.g., PostGis) and provide basic access operators (e.g., find road segment, route computation, aggregation functions, etc.) for all user requests. To accomplish these things, the authors will rely on open-source software such as JavaScript, Apache WebServer, Apache Tomcat, GeoServer, PostgreSQL/PostGis, etc. However, monthly fees for utilized online storage and computational resources will apply.

4.5 Framework of Map Evaluation Tool

The interface of the MET will have three major components: (i) *Input-based component*, where the user can specify particular requirements for performance measures that he/she wants to retrieve; (ii) *Map-based component*, where the investigated performance measures will be displayed and visualized; (iii) *outcome-based component*, where statistics and other results are displayed in the corresponding diagrams and tables. Figure 4-3 shows the input-based component

¹² <https://en.wikipedia.org/wiki/Model%E2%80%93view%E2%80%93controller>

(left side), map-based component (central), and outcome-based (right side) component of MET. The following text explains these components in more detail.

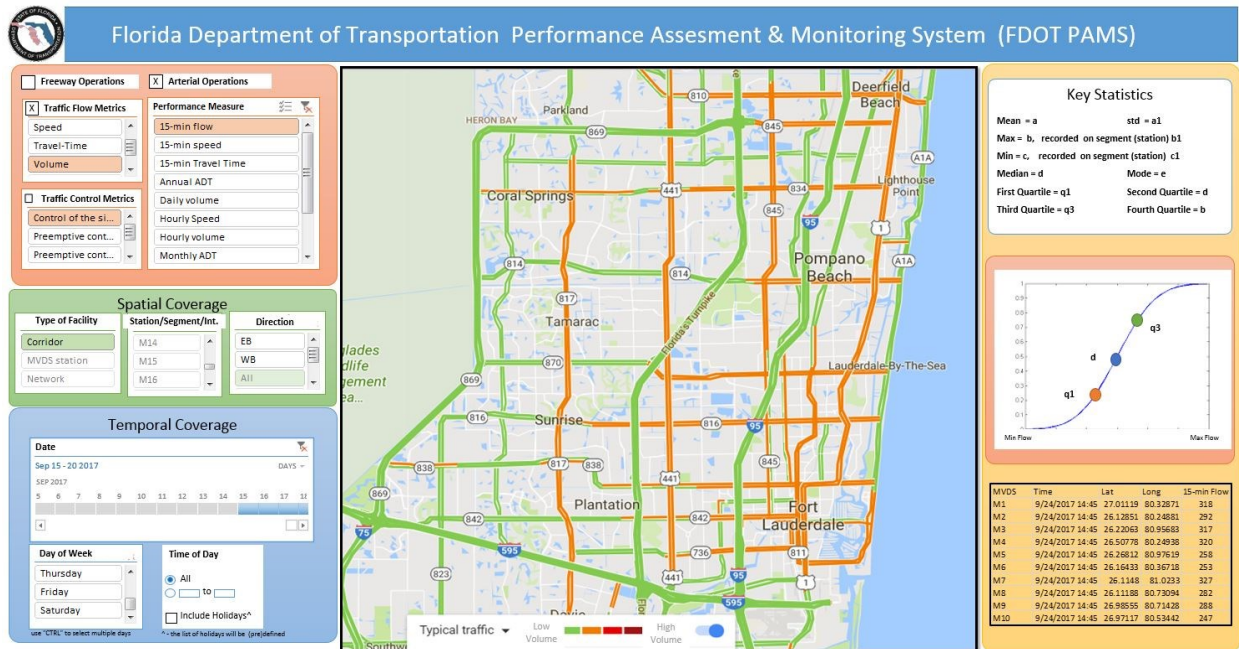


Figure 4-3: Layout of the Map Evaluation Tool

4.5.1 Input-based Component

The MET will be developed as a user-oriented web tool that will provide a wide variety of performance measures (discussed in more details in Section 3) and high flexibility in respect to spatial and temporal data aggregation. A user (operator) who needs to make a request or inquiry will need to specify the following parameters: (i) measures that need to be investigated; (ii) spatial-aggregation – portion of the network where the performance measures (defined in (i)) will be computed; (iii) temporal aggregation – time intervals that will be considered in computation of performance measures (defined in (i)). Noteworthy, the spatial aggregation depends on the selected performance measures. For example, volume and occupancy data will be aggregated for point-like stations while the travel time data will be aggregated for various links and segments in the network.

4.5.1.1 Selection of Performance Measures

The MET will be capable of computing the performance measures that: (i) use historical data (past or historical module of the MET); (ii) rely only on real-time data (present or real-time module of MET); and (iii) refer to the time instances in future (predictive or future module of MET).

A list of the performance measures as a historical module is shown in Figure 4-4. These performance measures are grouped into two subgroups: *Traffic Flow Measures* and *Signal Control Measures*. For instance, Volume-based performance measures consist of: (a) 15-minute flow; (b) hourly volume; (c) daily volume; (d) Annual Average Daily Traffic (AADT); (e) the ratio of

observed, or recorded, to expected, or historical, volume; and (f) Volume Percentile¹³ (see Figure 4-4 and Sections 3.4 for more details). The circle symbol refers to the radio button while the square denotes the check box. Please note that in the context of radio button users can select only one option while using checkboxes they can selected multiple of available options.

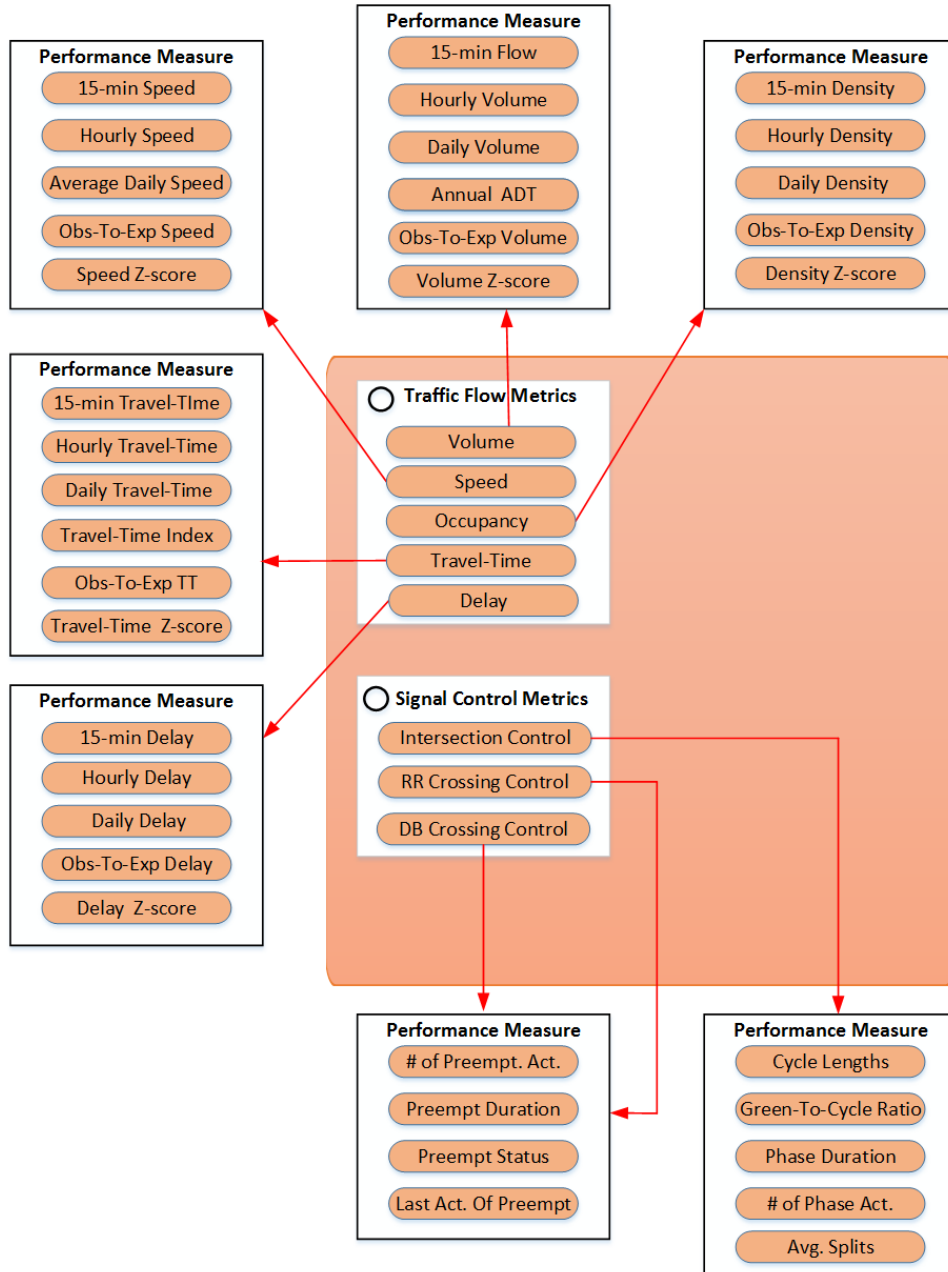


Figure 4-4: Performance Measures for the Past Module of MET

The MET will present real-time data within the map, and associated statistics will be shown in the relevant figures and tables. The present MET module will rely on the sources of real-time data

¹³ <https://en.wikipedia.org/wiki/Percentile>

described in Section 4.1.1. Figure 4-5 presents the performance measures within the present (real-time) module within MET.

The predictive module of the MET will utilize real-time and historical data and commonly used prediction algorithms, such as moving average and support vector regression, for assessing the future traffic parameters for the predefined prediction horizons of 15 and 30 minutes. Figure 4-6 presents the performance measures within the predictive module of MET.

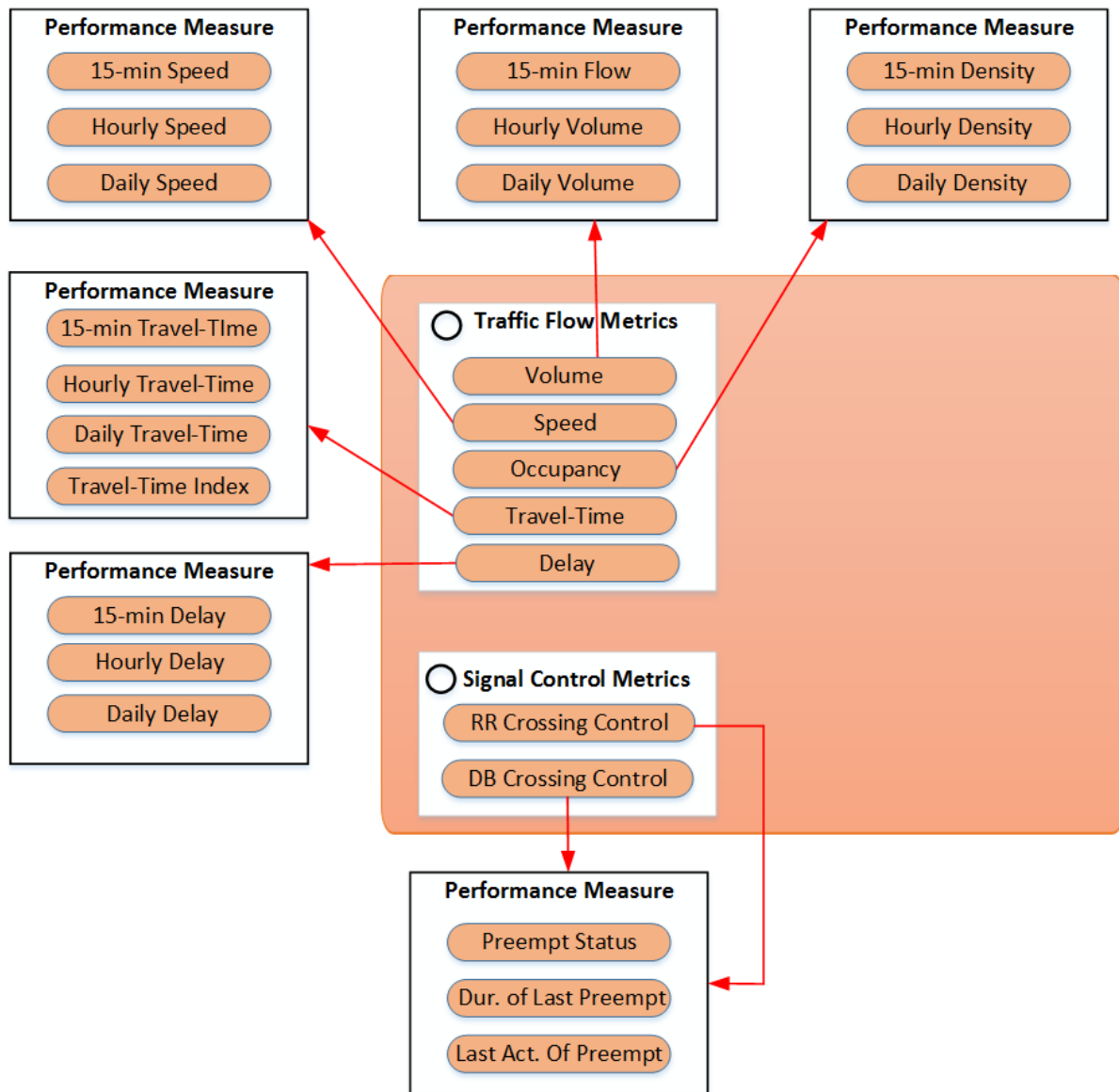


Figure 4-5: Performance Measures for the Present Module of MET

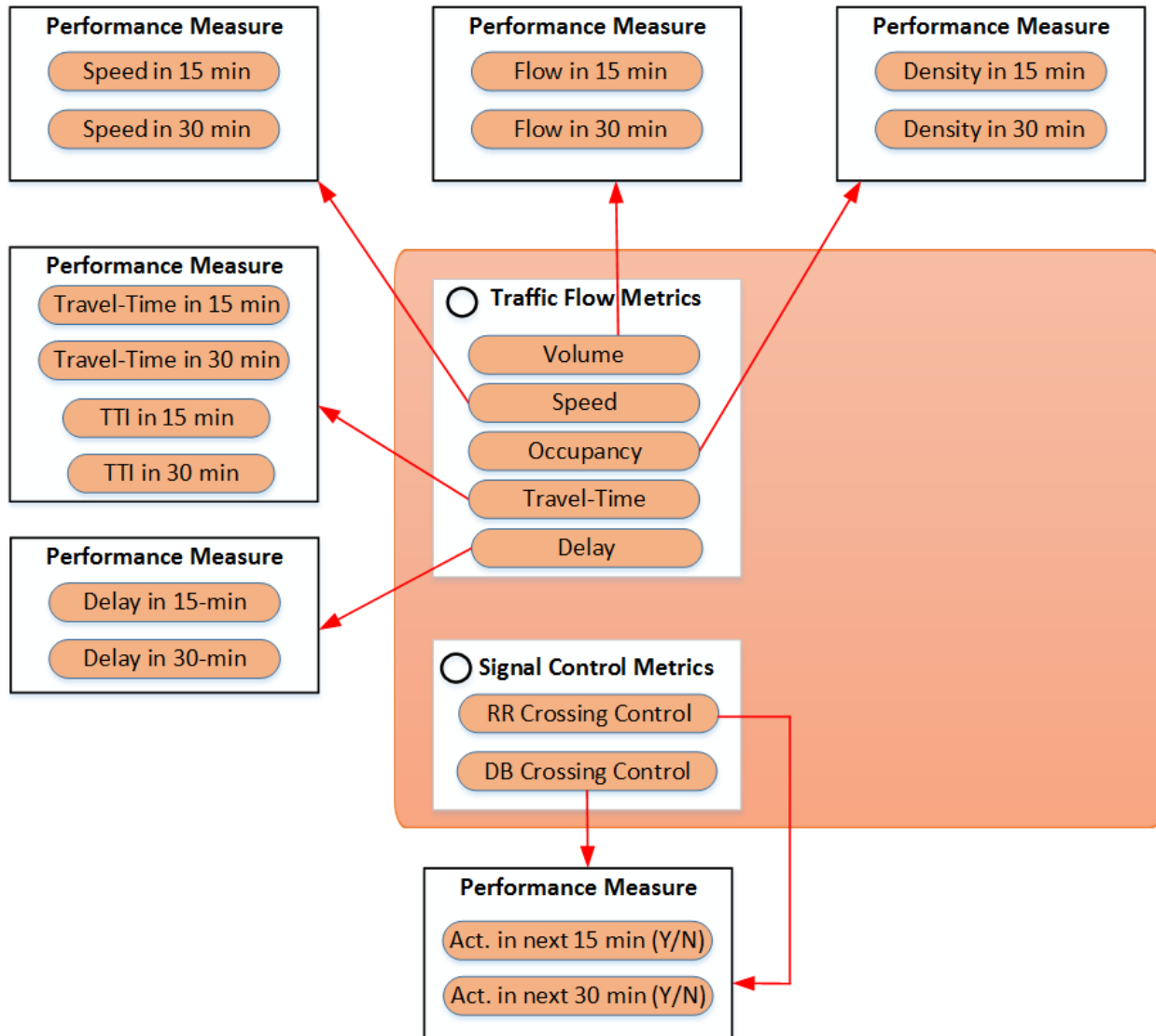


Figure 4-6: Performance Measures for the Future Module of MET

4.5.1.2 Spatial Data Aggregation

Once a user selects a performance measure, they will need to select the spatial coverage of the network for which the selected performance measure needs to be retrieved. Hence, the selection of spatial aggregation options available to the user depends on the performance measures that the user selected in the previous step. Figures 4-7 and 4-8 show the spatial aggregation options for each performance measure (see red arrows in Figure 4-7) and how these spatial aggregates can be further filtered based on the type of relevant facility (see red arrows in Figure 4-8). Even this spatial disaggregation can be further decomposed by the direction of traffic streams in each facility (see the blue arrows in Figure 4-8).

In general, the MET will be capable of reporting performance measures on three different levels:

- a) Individual facility level – a single road segment or an MVDS station
- b) Corridor level – all road segments or MVDS stations along Sunrise Blvd.
- c) Network level – all road segments / MVDS stations in the network.

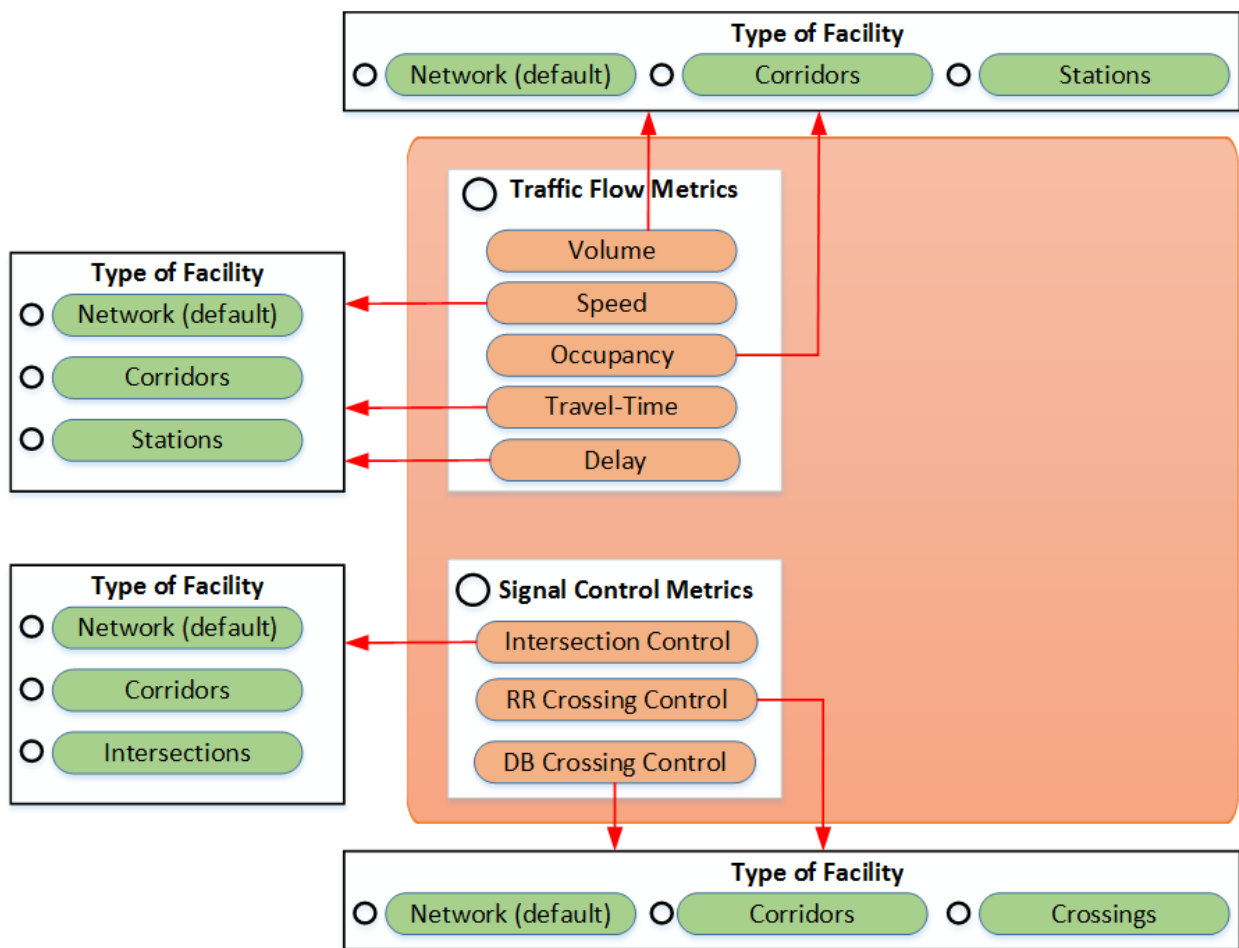


Figure 4-7: Spatial Data Aggregation Options for Various Performance Measures

There could also be minor variations in the proposed data aggregation. In the context of single facility levels, a user will also have flexibility to choose multiple facilities (e.g., 2-3) for analysis (see Figure 4-8). Similarly, in the context of corridor-level data aggregation, a user can select either of the two directions along the selected corridors (see Figure 4-8). Figure 4-7 and Figure 4-8 show that the default value (if nothing has been selected) is analysis of the *entire network*.

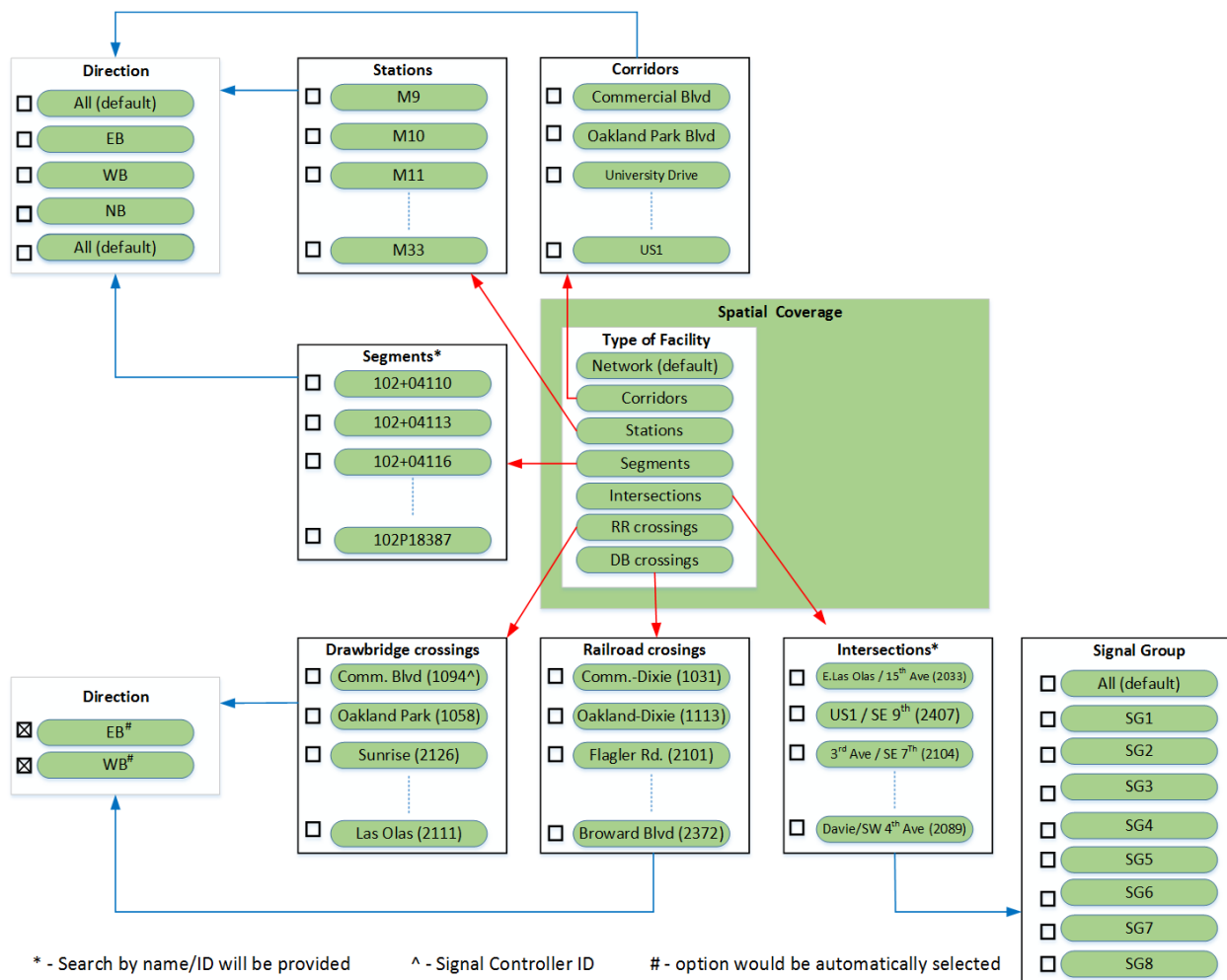


Figure 4-8: Directional Spatial Data Aggregation

4.5.1.3 Temporal Data Aggregation

In addition to spatial data aggregation, a user will have high flexibility in defining an analysis period for the retrieval of a selected performance measure. Figure 4-9 shows the options that a user can select. First, the start and end dates of the analysis period are selected. Then, a user selects a single day or multiple days of a week that will be taken in consideration (see Figure 4-9). The user

can also specify either the entire day or one of its intervals to be considered in the analysis. Finally, a user can opt to include or exclude public holidays¹⁴ in the analysis. Similar to in spatial data aggregation, the entire period is a default option, which is assumed if none of the available options is selected.

The image shows a user interface for selecting temporal data aggregation options. It is divided into two main columns. The left column contains 'Start date:' with input fields for MM, DD, and YYYY, followed by 'Day of Week' with a list of radio buttons for 'All (default)', 'Monday', 'Tuesday', 'Wednesday', 'Thursday', 'Friday', 'Saturday', and 'Sunday'. The right column contains 'End Date' with input fields for MM, DD, and YYYY, followed by 'Time of Day' with radio buttons for 'Entire day' and a time range 'hh:mm - hh:mm', and a checkbox for 'Include Holidays'.

Figure 4-9: Available Temporal Data Aggregation Options

Once a user selects a performance measure and desired spatial and temporal aggregation, they would need to press the “Update” button to initialize data retrieval, computational procedures, a visualization of the performance measures (discussed in section 4.5.2), and associated statistics (discussed in section 4.5.3).

¹⁴ <https://www.redcort.com/us-federal-bank-holidays/>

The broad temporal data aggregation is available only within the historical module of the MET. If none of the temporal-related parameters is selected, then the most recent data for a single time instance will be considered as a default setup. For a present, real-time module, data will be presented for the current or most recent time instance. In the context of predictive modules, a user will be able to specify a single time instance in the future (e.g. within the prediction horizon) for which predictions will be made.

4.5.2 Map Window within the MET Map-based Component

The central part of the MET will be a baseline map used for the visualization of analyzed performance measures. Only those facilities for which the performance measures are computed will be highlighted and visualized on the map. The traditional set of colors will be used to depict congestion along investigated facilities. For instance, dark red will represent heavy congestion while the light green color will depict free-flow or near free-flow conditions. A user will have the option to select one of the available maps from the predefined lists comprised of ArcGIS World Street Map, Bing Map, Open-Street Map, etc. (shown in Figure 4-10 and Figure 4-11). In addition, a user will be able to zoom in or out to better observe a certain facility's performance. The drawing scale and latitude and longitude coordinates will also be provided on the underlying map (see Figure 4-10 and Figure 4-11).

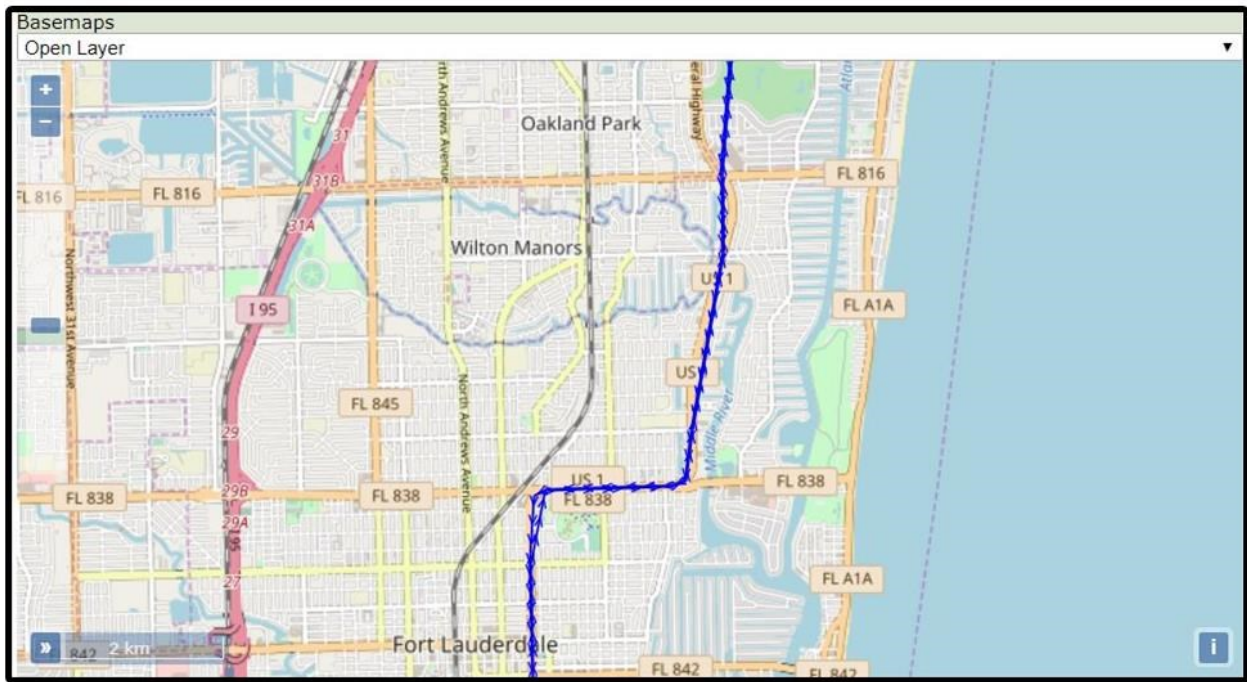
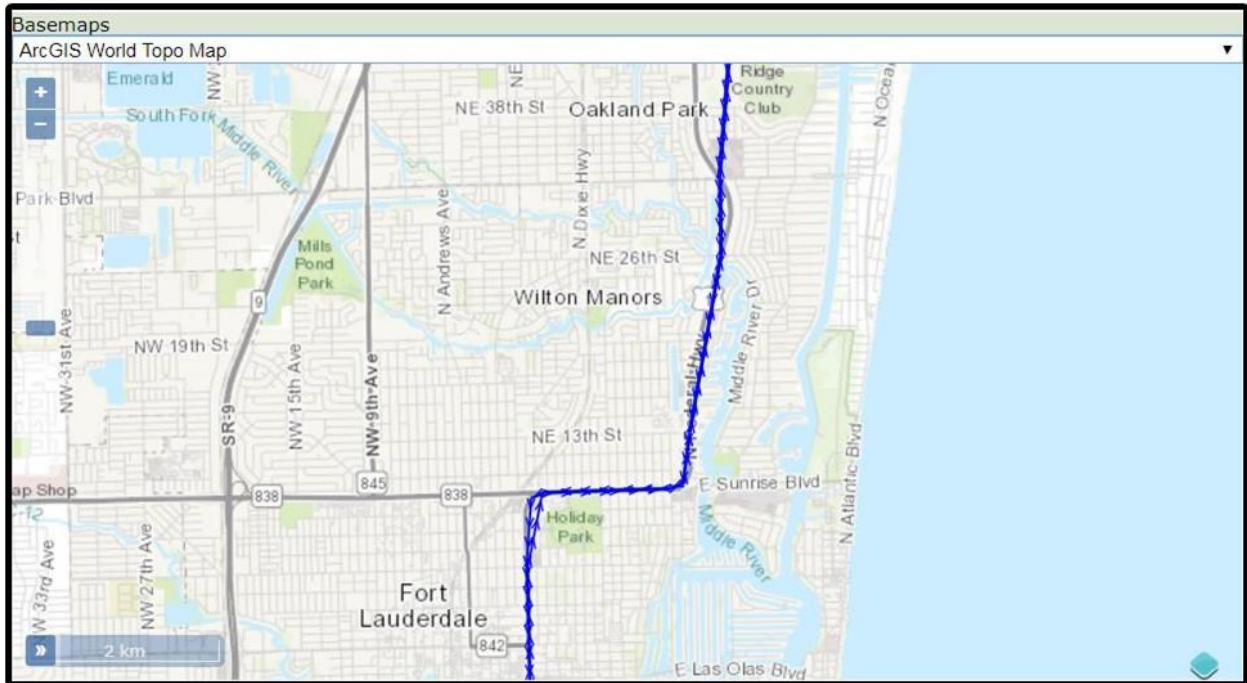


Figure 4-10: World Topo Map (*top*) and Open Layer (*bottom*) Basemaps

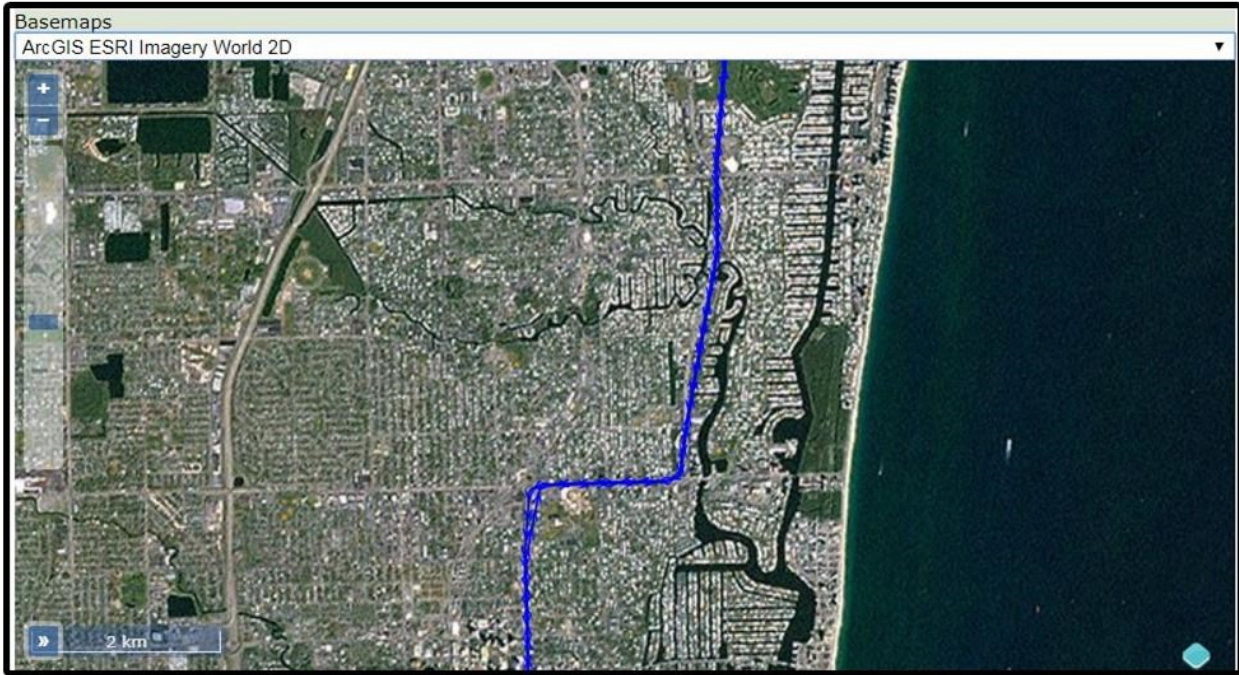
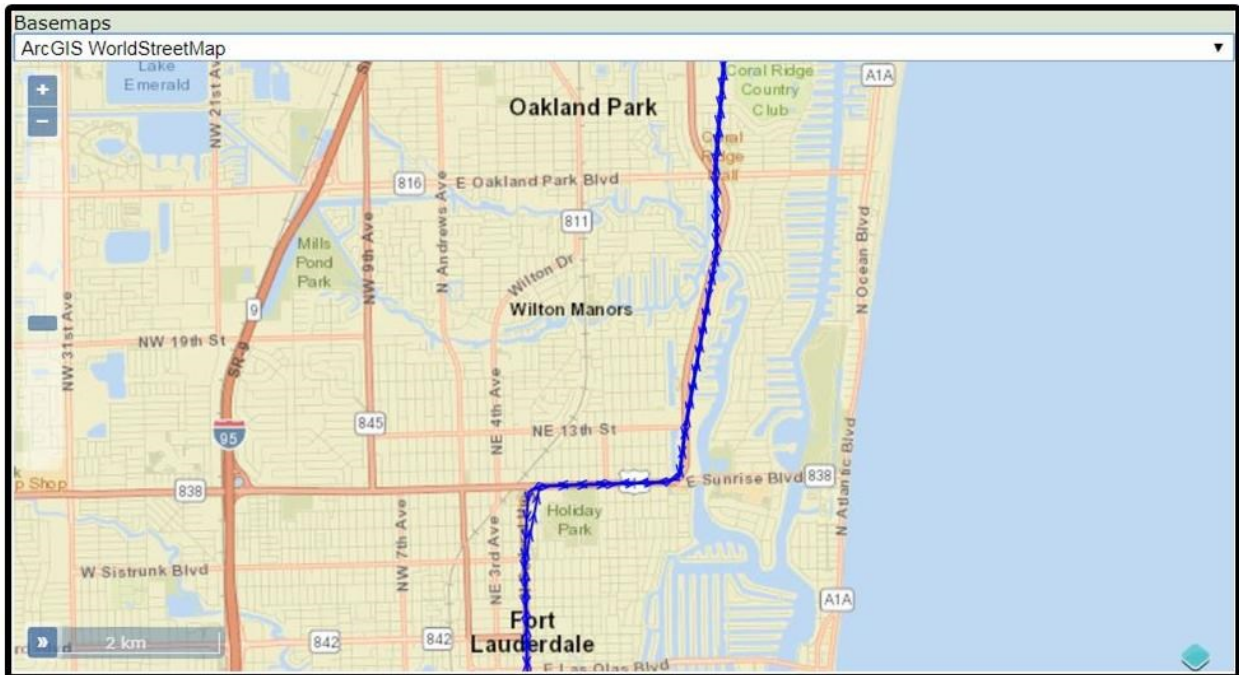


Figure 4-11: World Street (*top*) and Imagery World 2D (*bottom*) Basemaps

4.5.3 Map Evaluation Tool Chart Window

Once a performance measure is selected and visualized on the map, the appropriate graphical and tabular representation of the selected performance measure (for selected spatial and temporal filters) will be presented. Numerous diagrams, shown in Figure 4-12, will be available to help users better understand traffic conditions.

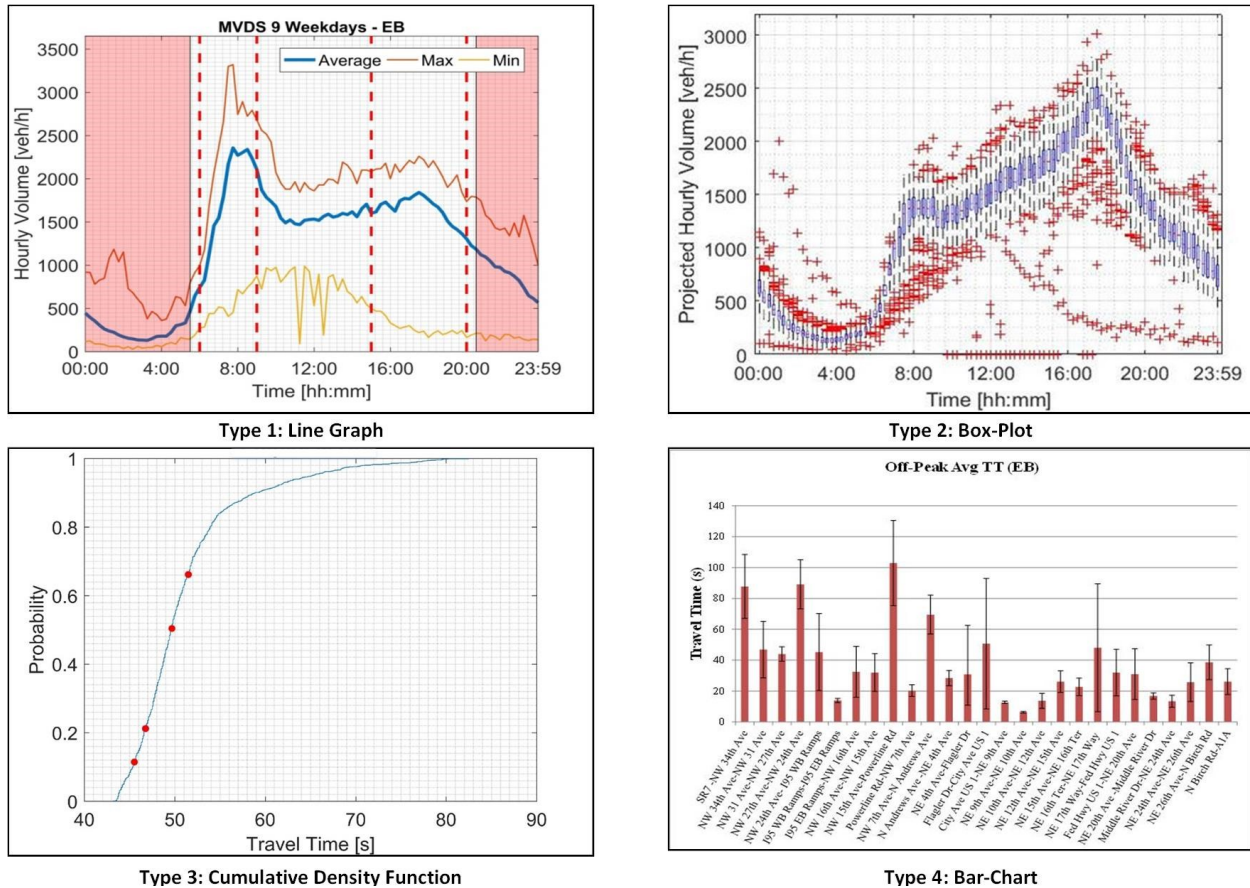


Figure 4-12: Variety of Charts for Map Evaluation Tool Chart Window

The type of chosen graph (from selection shown in Figure 4-12) is a function of selected performance measures and desired spatial and temporal aggregation levels. For instance, if an operator wants to investigate 15-minute traffic flow (collected from MVDS stations) in the entire network and for multiple time instances within a single day or multiple days, then the most appropriate graphs would be a line graph (see type 1 in Figure 4-12). In the real-time or predictive module, the users observe the traffic conditions during a single time instant so the bar charts will be used for these applications.

Certain graphs and tables will be embedded in daily and monthly reports, which will help traffic operators better understand traffic conditions in the far and near past. The layout of these reports will be similar to the layout of the reports generated by SunGuide, shown in Figure 4-13.

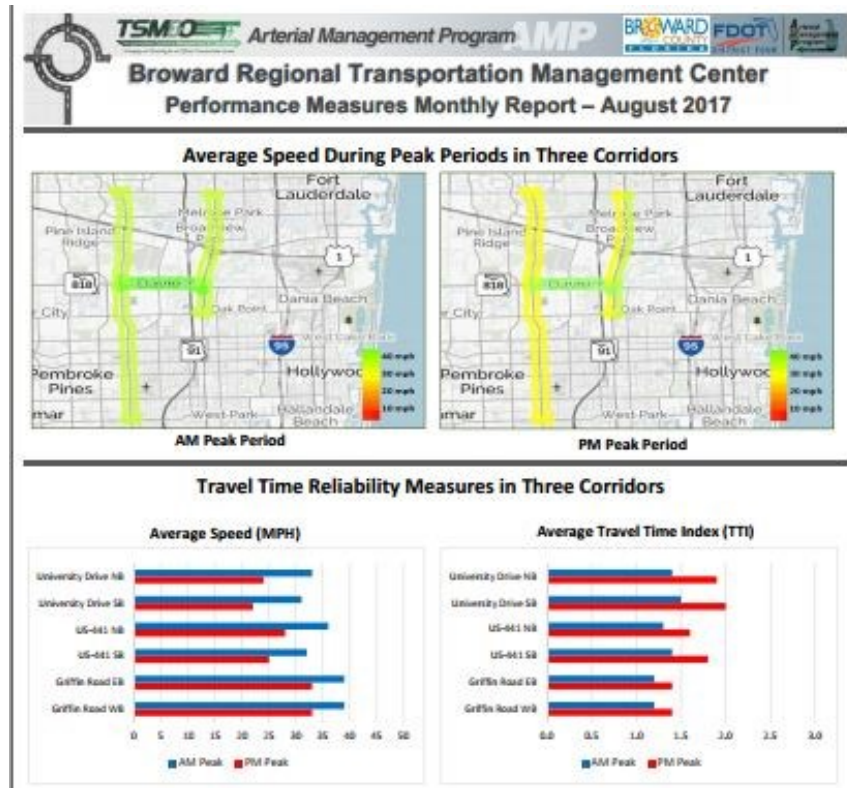


Figure 4-13: The SunGuide Report¹⁵

4.6 An Example of Map Evaluation Tool Set-up

To summarize the underlying mechanism and component of MET, the authors present the following example. Figure 4-14 depicts a scenario where an operator wants to investigate 15-minute flow data from all MVDS stations in the network during the entire period. Filtering inputs are defined on the left side of Figure 4-14. Based on this selection, an average one-directional 15-minute traffic flow data are visualized for each station on the base map, located in the central part of the MET and Figure 4-14. Green refers to the stations with average low volume, whereas red is assigned to stations with average high volumes. The key statistics are given in the top right part of the figure. The most relevant graphical representations of selected data are given below the statistics (see Figure 4-14).

¹⁵ <http://www.smartsunguide.com/#/arterials>

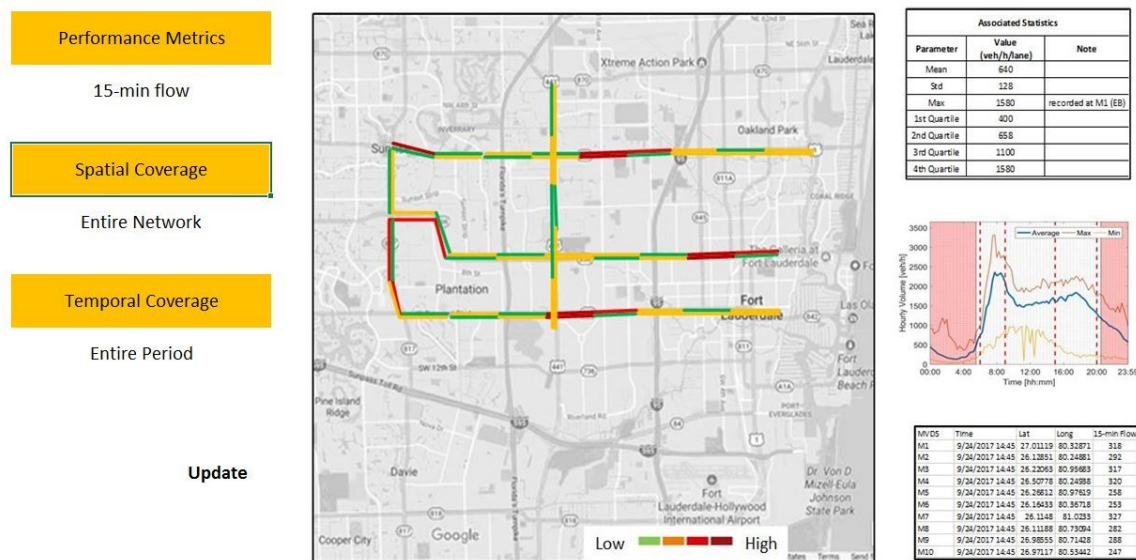


Figure 4-13: Conceptual Example of MET Layout

4.7 Potential Applications of Map Evaluation Tool

The MET is essentially a framework that will allow TMC operators to query traffic data (both current and archived), compute arterial performance measures, and conduct various analyses. Operators can observe colored maps and extract diagrams and summary reports related to the current and/or historical traffic conditions (i) along (Here/RITIS) road segments; (ii) near MVDS stations and preempted crossings; and (iii) at major signalized intersections. In particular, the following are some of potential applications of the MET:

- The MET will serve as a monitoring tool – the real-time data will be processed and presented on the map.
- The MET will be capable of computing performance of the entire system/network expressed in volumes, speeds, delay, travel times and average daily traffic (AADT). Operators can use extracted performance measures for model calibration, verification of external study findings, and assessment of overall traffic conditions.
- The MET will be used to calculate travel time and travel time reliability measures, such as the Travel Time Index, and other descriptive statistics.
- Relationships between the observed real-time and expected traffic parameters in terms of historical averages will be quantified and visualized on the map and in graphs. This information will help operators identify unusual conditions in the network.
- The MET will allow operators to assess the status (activation) of most of the preempted crossings in the network.
- The MET will provide the statistics (e.g., mean, standard deviation) of the historical activations of drawbridge and railroad crossings.

- The MET will provide information on average daily traffic (AADT). Such data can be conveniently used as inputs in simulation models and other consulting projects.
- The MET will be able to generate daily and monthly summary reports that contain frequently used performance measures aggregated on various spatial and temporal levels.
- The MET will be able to identify and replace (i.e., by using the historical average method) missing data in real-time.
- The MET will provide a historical speed for most of the segments in the network as reported by RITIS and real-time updates that are provided by HERE. MET will allow for a comprehensive spatial and/or temporal analysis on these imported data sets.
- The MET will allow users to locate the incidents from SunGuide data sources.
- The MET will support integration with common Internet-based mapping services (e.g., Bing, OSM)
- The MET will provide a scalable and robust framework so that new types of traffic data can be embedded in future.
- The MET proposed framework will be developed in such a way that it is expandable (spatially) or can be applied for new study areas.

4.8 Current Version of the Map Evaluation Tool

Some of the components discussed in Section 4 have already been implemented in the initial version of MET. Figure 4-15 shows the screenshot of a very early version of MET. As Figure 4-15 shows, some progress has been made on designing the user interface (left part of Figure 4-15) as well as mapping- and statistics-based components, shown in the central and right areas, respectively, of Figure 4-15. The MET currently resides on a local server, but it will be moved to a cloud platform in near future. The logo of the Florida Department of Transportation will be in the left upper corner of the MET window.

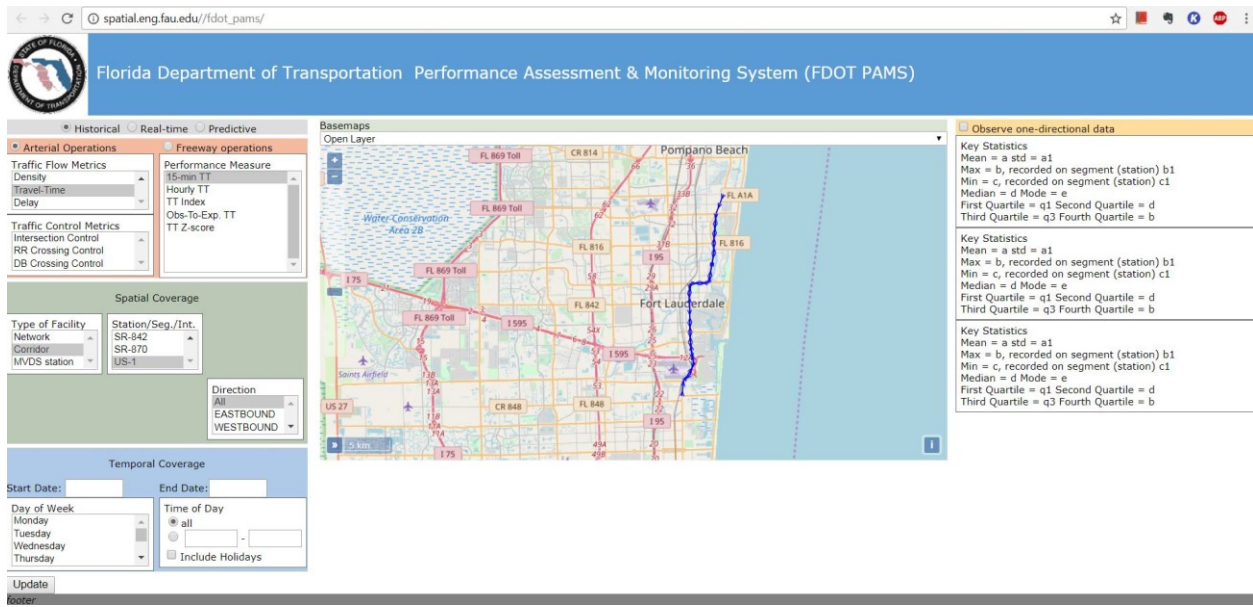


Figure 4-14: An Early Version of Map Evaluation Tool (May 2018)

Multiple names for the MET have been considered, and the current working name is FDOT-PAMS, which stands for Florida Department of Transportation **P**erformance **A**ssessment and **M**onitoring **S**ystem. The abbreviation is similar to the famous traffic platform Caltrans Performance Measurement System (CalTRANS – PeMs). Other potential names under consideration for the MET include:

- FDOT-METTMC: Florida Department of Transportation **M**onitoring and **E**valuation **T**ool for **T**raffic **M**anagement **C**enters
- FDOT-MEFHAN: Florida Department of Transportation **M**onitoring and **E**valuation **F**ramework for **H**ighway & **A**rterial **N**etworks.

5. DEVELOPED SCRIPTS AND MODULES WITHIN MAP EVALUATION TOOL

Map Evaluation Tool (MET) is a traffic platform furnished with diverse and heterogeneous databases containing traffic-related information for arterial and freeway networks in Broward County. The developed databases are populated with historical traffic information, and continuously updated with the real-time information. These databases are stored on the (Microsoft Azure) server, which is also considered as a back-end component of the developed MET framework. The front-end component, which the client views, is deployed in the form of a website. The programming scripts required to build this quite comprehensive platform can be categorized into three distinctive groups as follows:

1. Scripts used to construct databases and populate them with historical traffic data
2. Scripts used to update databases (developed in step 1) with real-time information.
3. Scripts used to build the website and connect databases (developed in steps 1 and 2) and user interface.


In the following sections, the FAU research team describes each of these sets of scripts in more details.

5.1 Scripts Used to Construct Databases and Populate them with Historical Traffic Data

The FAU research team uses PostgreSQL¹⁶ to construct, store, and process the relational databases. The PostgreSQL scripts are used to construct the databases by assigning the column name and type of data that can be used to populate each of these columns. This table's layout is often referred as a "schema". Figure 5-1 shows one instance of PostgreSQL codes developed to construct the schema for MVDS data. To this end, the FAU research team constructs the empty tables in PostgreSQL.

The Java codes are developed to populate empty PostgreSQL databases with historical data. The historical datasets, provided by FDOT and RITIS (HERE) in the forms of *.csv*, *.txt*, and associated *.kml* files, are parsed and then embedded in the PostgreSQL databases. Figure 5-2 shows the screenshots of the developed Java codes (*left*) and produced databases in PostgreSQL platform (*right*).

¹⁶ SQL = Standardized Query Language



The screenshot shows the Eclipse IDE interface with a SQL editor open. The editor displays three CREATE TABLE statements for a PostgreSQL database. The first table, mvds.mvds_historical_detector_id, has columns for zone_id, display_name, state, rtmc, timezone, road, dir, loc_desc, lane_type, org, detector_type, latitude, longitude, bearing, default_speed, inter, length, study_area, and geom. The second table, mvds.mvds_historical_zone, has columns for zone_id, measure_start, speed, volume, occupancy, vol_weighted_speed, and fact_vol. The third table, mvds.mvds_historical_lane, has columns for zone_id, lane_num, lane_id, measure_start, speed, vol, occ, vol_weighted_speed, and fact_vol. The IDE window title is 'eclipse-workspace - fdot_pams_dataset/src/historical/mvds/sql/schema.sql - Eclipse IDE'.

```
1 CREATE TABLE mvds.mvds_historical_detector_id (  
2   zone_id varchar(5),  
3   display_name varchar(254),  
4   state varchar,  
5   rtmc varchar,  
6   timezone varchar,  
7   road varchar,  
8   dir varchar(5),  
9   loc_desc varchar,  
10  lane_type varchar,  
11  org varchar(4),  
12  detector_type varchar,  
13  latitude double precision,  
14  longitude double precision,  
15  bearing varchar,  
16  default_speed integer,  
17  inter integer,  
18  length double precision,  
19  study_area boolean,  
20  geom geometry(Point,4326));  
21  
22 CREATE TABLE mvds.mvds_historical_zone (  
23   zone_id varchar,  
24   measure_start timestamp,  
25   speed double precision,  
26   volume double precision,  
27   occupancy double precision,  
28   vol_weighted_speed double precision,  
29   fact_vol double precision);  
30  
31 CREATE TABLE mvds.mvds_historical_lane (  
32   zone_id varchar,  
33   lane_num varchar(1),  
34   lane_id varchar,  
35   measure_start timestamp,  
36   speed double precision,  
37   vol double precision,  
38   occ double precision,  
39   vol_weighted_speed double precision,  
40   fact_vol double precision);  
41
```

Figure 5-1: PostgreSQL codes for Constructing a Database

The developed Java codes are located in the “*fdot_pams_data*” folder. These scripts include¹⁷:

- **Bridge and railroad preemption data** are extracted from historical emails. The **time stamps** of preemptive activation and deactivation of railroad and drawbridge **crossings** are extracted from these emails. The latitude and longitude of the crossings were provided in the form of *.kml* maps. The developed Java codes are used to make the dynamic SQL queries to populate the PostgreSQL databases. These java codes are located in the java packages: **bridge.kml**, **bridge.loc** and **bridge.mail**.
- **MVDS** data for arterial and freeway network are downloaded from the RITIS website for the period of almost three years (Jan. 2016 – Oct 2018). The 15-minute volume and density information (per group of lanes) are parsed from the historical *.csv* & *.txt* files and embedded in the PostgreSQL tables. For all MVDS stations presented in the network, the associated latitude and longitude coordinates are provided in the corresponding *.kml* files. The Java codes used to process historical MVDS data are given in the java packages: **historical.mvds**, **mvds.detector**, **mvds.detectorId**, **mvds.detectorLocation**, **mvds.zone.loc**.
- **MVDS - Weekly Historical Averages Data** – The Python scripts are developed to process the historical MVDS data (for the period of almost three years) in order to compute the average one-directional traffic flow and density for a particular MVDS station during each 15-minute interval within a week. For instance, the average volume associated with 15-minute interval at Station A from 2:15 – 2:30 PM on Monday is an average of all volumes recorded at the Station A during this time period on each Monday during the period of almost three years. The public holidays are not excluded from this analysis since their impact is often minor in the large databases. The computed data (along with associated statistics such as standard deviation) is then embedded in the SQL databases using the Java scripts, located at the **mvds.histaverage** java package. The weekly historical averages data are used to compute predictive based performance measures.
- **HERE - Traffic Message Channel (TMC)** data comprises speed and travel time information for the freeway and arterial segments in the network. The historical HERE information is recorded for the period of almost three years and embedded in the PostgreSQL databases using java scripts (located in the **tmc.loc** java package). The associated latitudinal and longitudinal information is also provided in the PostgreSQL tables within HERE and topology schemas (see PgAdmin4 interface in Figure 5-2).
- **HERE - Weekly Historical Averages Data**. Similar to historical MVDS data, the Python scripts are developed to compute the average historical speed and travel time information for each segment in the network during each 15-minute interval within a week. Then, these values and associated statistics are used to populate the corresponding PostgreSQL tables with the help of java codes (located in the **tmc.hist_average** java package).

¹⁷ In alphabetical order as given in Eclipse Workspace

5.2 Scripts Developed to Update the Database with the Most Recent Traffic Information

Once the PostgreSQL database is constructed and populated with historical information, it needs to be continuously updated with the most recent or real-time data available. In this regard, the java scripts are developed to periodically (e.g. every 2-3 minutes) access the most recent traffic data, parse the relevant information, and then use this revealed information to populate the existing PostgreSQL database (developed in Section 5.1). Figure 5-3 shows the developed codes in java (*left*) and produced databases in PostgreSQL platform (*right*). These scripts are located in the “*fdot_pams_data*” folder and they include:

- **Bridge and railroad preemption scripts** that parse the activation and deactivation of the railroad and drawbridge preemption activation provided via email. These scripts also use the revealed information to populate / update the existing PostgreSQL preemption-related databases. It is noteworthy that to access the information of the activation of drawbridge and railroad data, the FAU research team used a username and password associated with the a google e-mail address and embedded this information in the Java codes. The bridge and railroad preemption java scripts are located in the **pams.bridge.realtime.action**, **pams.bridge.realtime.dao** and **pams.bridge.realtime.dao.sql** Java packages.
- **HERE related scripts** parse real-time speed and travel-time data from the HERE data source. The URL that contains most recent real-time information is periodically accessed using the provided credentials that are embedded in the Java codes. The downloaded traffic data are processed, and the relevant information is utilized to prepare the PostgreSQL script. By executing these scripts (through java codes) the FAU research team embedded the new, or real-time, information in already constructed HERE tables within PostgreSQL relational database. HERE related Java scripts are located in the **realtime.here**, **pams.realtime.here**, and **realtime.here.*** java packages.

The MVDS-based data are not provided in real-time. Some initial efforts were made to develop the Java scripts (in the *sftp.main* class) that can parse the volume and density data and populate the PostgreSQL databases, if the access to real-time MVDS data is provided in the future.

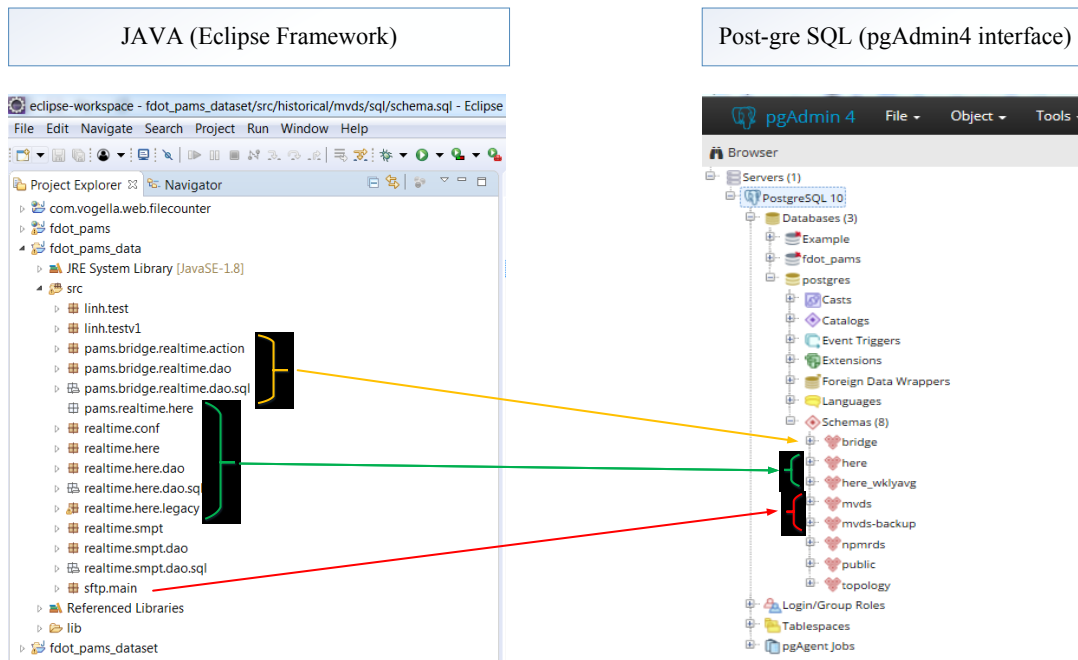


Figure 5-3: Developed Java Codes to Update PostgreSQL Databases with Newest Data

5.3 The MET User Platform

Once the databases are constructed and populated with historical and most recent data, the FAU research team developed the client-viewable website that allows users to set their input, extract relevant information from the databases, and present this information and associated performance measures on the underlying map and in the form of associated statistics. To extract the relevant information from the databases, one needs to: (i) set the inputs on the MET website; (ii) run the query; (iii) process the output on the server side; and (iv) visualize the explicit and derived results from the query on the client side (front-end or website). Figure 5-4 shows these high-level technical steps and action, which are performed on the client and server sides. This figure can help users and programmers better understand the organization of the Java codes developed for the MET tool. Figure 5-5 shows the key steps within the MET tool (*left*) and associated scripts that allow for the realization of these steps. It shows operations that are performed on the client side (*red*) and the server side (*blue*) and lists the scripts associated with the historical (*orange*), real-time (*yellow*), and predictive (*green*) modules.

In the following chapter, the FAU research team describe in more details the scripts used to construct and execute the queries and reveal the meaningful information from the results of the query. These revealed and derived information (or performance measure) are later presented on the map and used to produce the associated statistics and graphs. The list of developed scripts required to construct and execute the query and process the query results are located in the “*fdot_pams*” root folder. The developed scripts include (but not limited to):

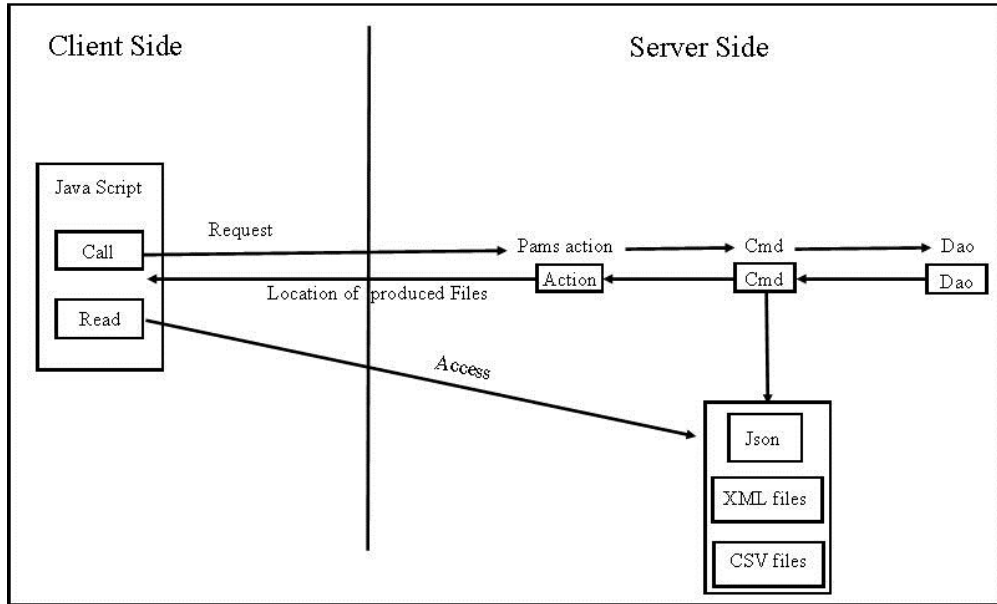


Figure 5-4: High-level overview of Map Evaluation Tool

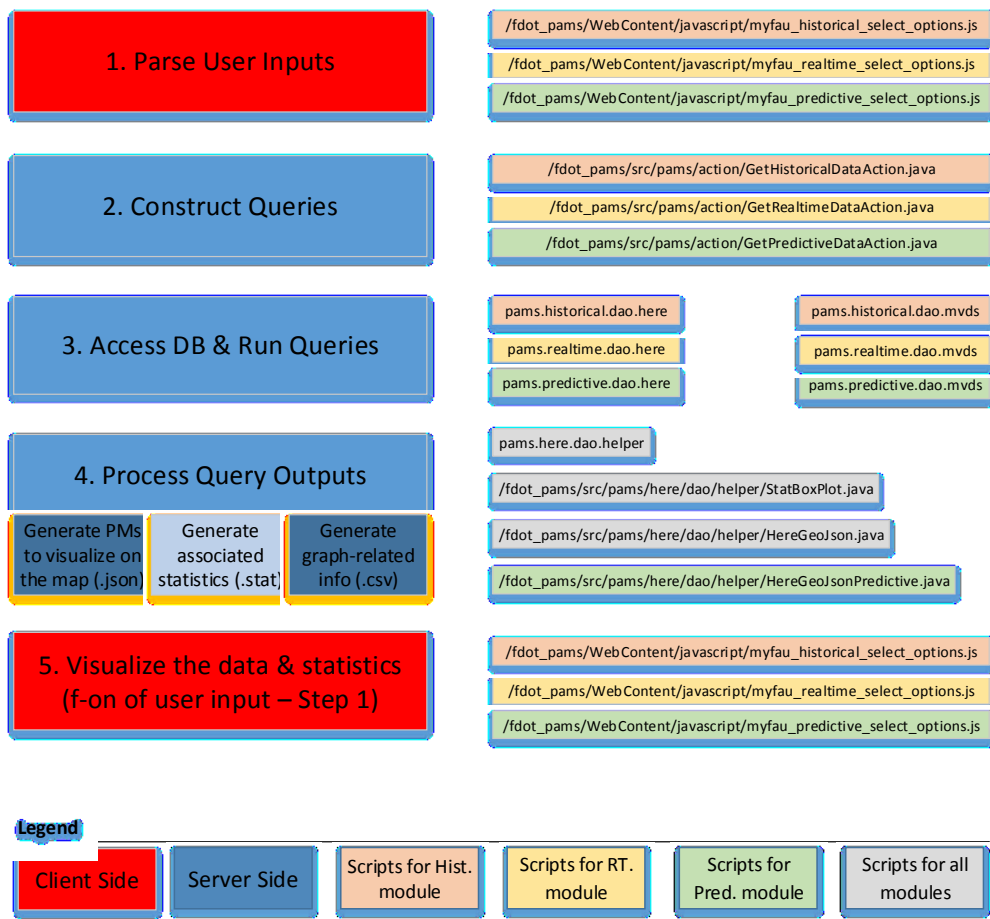


Figure 5-5: Key Steps and Associated Scripts

1. Root/WebContent/**Index.html** is the main document that contains links that allow the reader to jump to other places in the document or to another document altogether. HTML stands for Hyper Text Markup Language, and it defines the layout of the website. The *Index.html* document contains multiple static (e.g., title, FDOT logo) and dynamic elements (e.g., Map and user input's blocks) and allows users to select one of the *historical*, *real-time*, or *predictive* modules; then, the user can opt for the selected modules' performance measures and spatial and temporal aggregations as discussed in the previous chapters. The legend is coded in *Index.html* document, and it also needs to be set by user before (s)he hits the update button. The associated style and JavaScript documents are given in "*root/WebContent/css*" and "*root/WebContent/javascript*" folders, respectively.
2. Root/WebContent/javascript/myfau_*_select_options.js (where * = *historical*, *real-time* or *predictive*) is a JavaScript file that: (i) scans through the html file and parses the user inputs; and (ii) calls the corresponding java file based on selected user's inputs. This JavaScript file process the information about the performance measure, spatial, and temporal restrictions (if any) and legend thresholds and passes this information to further (Java) scripts.
3. Root/Src/pams/action/cmd/Get*DataAction.java (* = *historical*, *real-time*, or *predictive*) and the associated functions and scripts are developed to perform the following tasks:
 - a. **Construct the queries:** In a query, the user **selects** the certain attributes that need to be presented, **from** the set of provided tables and associated attributes **where** these attributes satisfy given requirements. Figure 5-6 shows a query and its major components. The queries within the MET tool are constructed by adding the user-defined temporal and spatial restrictions to the baseline query. Baseline query is constructed and stored in these Java packages that end in ".sql". Figure 5-7 shows one instance of the baseline query in the context of HERE data (*top left*) and user-defined spatial restrictions (coded in Java and presented on the *bottom right* side) that can be embedded in this baseline query. The performance measure is not explicitly taken into consideration in this step. Instead, the query is run to extract the multiple performance metrics for the imposed spatial and temporal restrictions.

```

SELECT c.tmc, ST_AsText(ST_Transform(c.geom,4326)), ct.speed, ct.tvltime_sec, ct.tvltime_sec -
ctm.min_tvlttime_sec, extract(month from ct.ts), extract(day from ct.ts), extract(year from ct.ts),
extract(dow from ct.ts), extract(hour from ct.ts), extract(minute from ct.ts), to_char(ct.ts,'HH24MI')

FROM npmrds.npmrds_network_here c, here.corridor_travel_realtime_data ct,
here.corridor_travel_data_minimum ctm

WHERE c.study_area = true AND c.tmc = ct.tmc AND ct.ts = (SELECT MAX(ts) FROM
here.corridor_travel_realtime_data) AND ct.tmc = ctm.tmc

```

Figure 5-6: An Instance of a Query

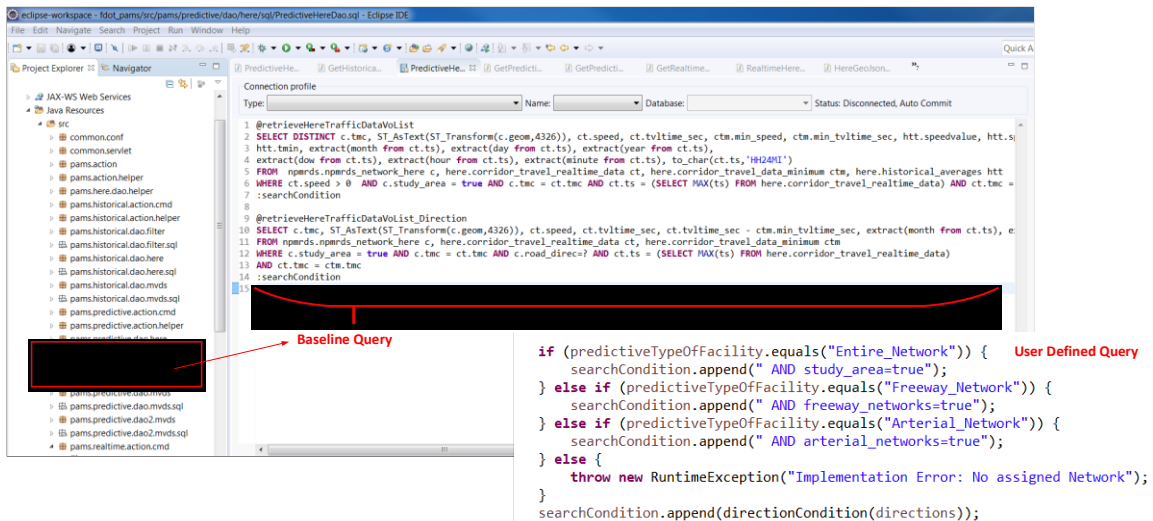


Figure 5-7: Baseline- (left) and User-defined (right) Query Components

- b. **Process the query responses.** The response of the query request is often given in the form of a matrix where the rows of this matrix refer to the facilities while the columns are associated with the particular “attributes”. Figure 5-8 (top) shows one instance of this matrix. We refer to this matrix as a Data Access Object (DAO).
- c. **Deriving the performance metrics from the Data Access Object (DAO) that will be visualized on the Map.** The data access object contains the explicit outputs from the query and needs to be further processed to produce the performance measures of interest. The set of Java scripts is developed to extract the multiple performance measures from DAO and store these metrics in a properly structured (Json) textual file. Figure 5-8 (bottom) shows a set of developed Java codes to process the query explicit responses.
- d. **Deriving descriptive statistics and graph-related data from Data Access Object (DAO).** Another set of Java codes is developed to extract the commonly used statistics (e.g., mean, std) from the DAO and save this information in the textual “.stat” file. Similarly, the relevant information required to construct the

graphs are also extracted from the DAO and saved in the form of “.csv files”. Figure 5-9 show one sample of created files (geoJson, .stat, and .csv) produced by Java Codes described in 3c and 3d. In this particular example the active module is “real-time”, the investigated performance measure is “speed” and the area of interest is restricted to “Freeway Network”. These attributes can be easily identified for a given filename. It is noteworthy that, although the selected performance measure is speed, the associated statistics and graph-related documents are created and for two other traffic parameters (delay, travel time) that are obtained from the HERE data source. In this way, the FAU research team potentially reduces the computation time of upcoming requests.

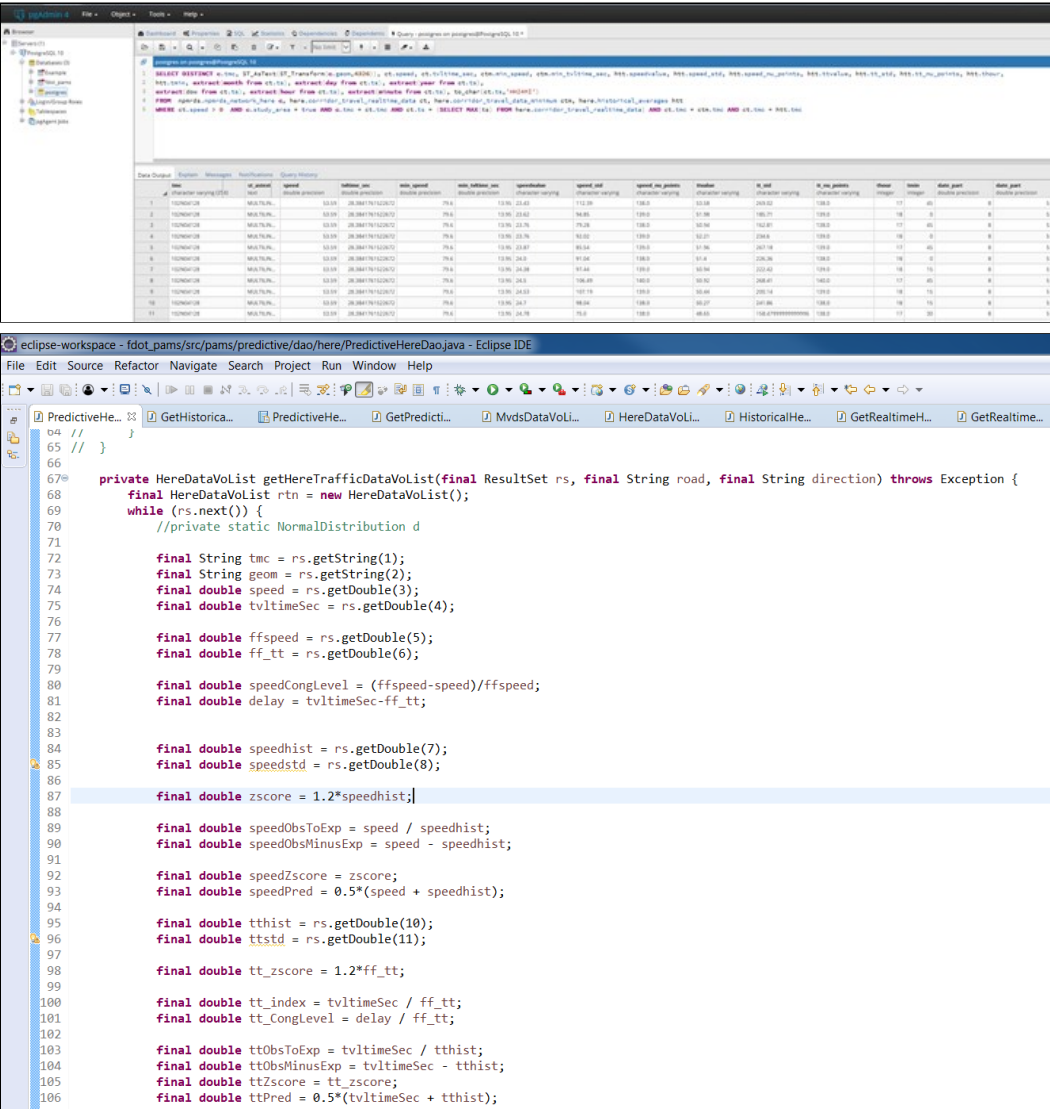


Figure 5-8: Query Output (top) is Used to Compute the Performance Measures (bottom)

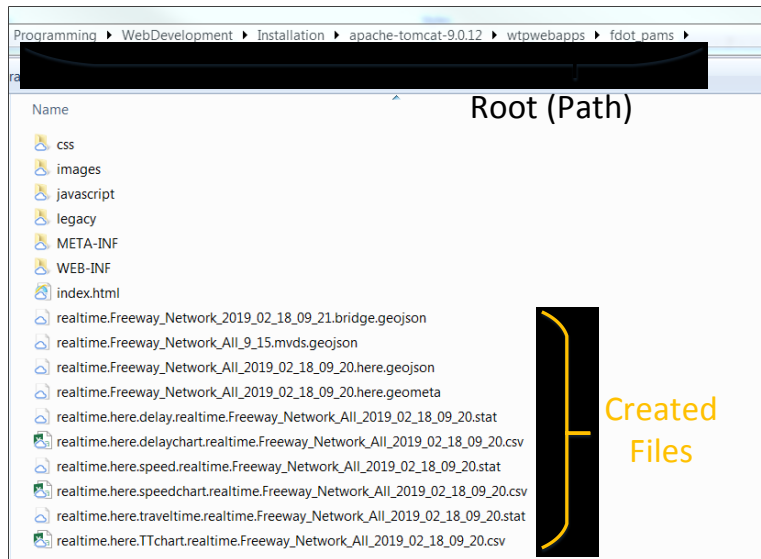


Figure 5-9: Created .geojson, .stat and .csv Files

Once the files required for map visualization (.geojson), statistics (.stat), and graph constructions (.csv) are constructed on the server side (see Figure 5-9), these files and their content need to be passed to the client side. Also passing on file location helps to efficiently transfer the required information, the FAU research team decided. In this way, even transferring the large files can be done quickly since the time required to complete this task does not depend on the size of the file. To this end, the FAU research team: (i) utilizes the user’s inputs to construct and run the query; (ii) processes the output of such query to construct the files required to visualize the data; present certain statistics, and develop the corresponding graphs; and (iii) passes the location of the constructed files from the server to the client side.

The JavaScript file, *Root/WebContent/javascript/myfau_*_select_options.js*, runs on the server side and is used to skim through the .html file and extract the user inputs as well as to visualize the data on the map for the selected performance measures. In other words, this JavaScript file uses nested if – end statements to examine the selected parameter or performance measure and runs the corresponding set of scripts associated with this (performance) metric. This set of scripts serves as input for the location of the corresponding files with the pre-stored information (explained in the previous section) in order to:

- (a) visualize the performance metric of interest on the underlying map (*central part of the website*)
- (b) populate the descriptive statistics box (*top-right box of the website*)
- (c) generate the corresponding graphs (*below the statistic box on the website*)

6. MANUAL FOR MAP EVALUATION TOOL

A user (e.g., an operator) can access the Map Evaluation Tool by typing the associated web address in the internet browser. It is recommended that the user refresh the website's homepage before making any query. The Map Evaluation Tool allows the user to make a variety of queries (explained in more detail in the rest of this chapter) whose outcome can help the operator better understand the traffic conditions and spot the unusual traffic situations observed at present time. In the following sections, the FAU research team provides a step-by-step guide for setting up these queries, and suggestions on how to interpret the results generated by MET for these queries.

6.1 Overview of the Layout and User-Defined Inputs in the Map Evaluation Tool

Figure 6-1 shows the major components of the Map evaluation tool (also discussed in previous chapters) and the tasks that a user needs to perform while setting up a query. As it can be seen from the left side of Figure 6-1, a user needs to:

- select the appropriate module (explained in Section 6.2),
- choose the performance measure to be investigated (explained in Section 6.3),
- define the region where the selected measure will be evaluated (Section 6.4),
- pick the period of time¹⁸ for which the selected measure will be analyzed (Section 6.5),
- configure the legend properly so that congested facilities can be easily spotted (Section 6.6),
- apply the selected input parameters (Section 6.7), and
- visualize the query results

In the following, each of these tasks is explained in more details.

6.2 Module Selection

Available modules are given in the gray tab located in the upper-left part of the MET website, immediately below the FDOT logo. The Map Evaluation Tool contains three modules: historical, real-time, and predictive (or estimated) modules.

- **Historical module** deals with historical data exclusively and produces the outcomes (performance measures) that refer to the time instant or period in the past.
- **Real-time module** presents the most recent data (provided in real-time) on the map without performing any significant computations.

¹⁸ This option is only possible within the historical module

- Predictive module** estimates how the present (or most recent real-time) data align with the corresponding historical averages and predicts the near-future traffic conditions. In both applications, the predictive module utilizes historical and real-time data.

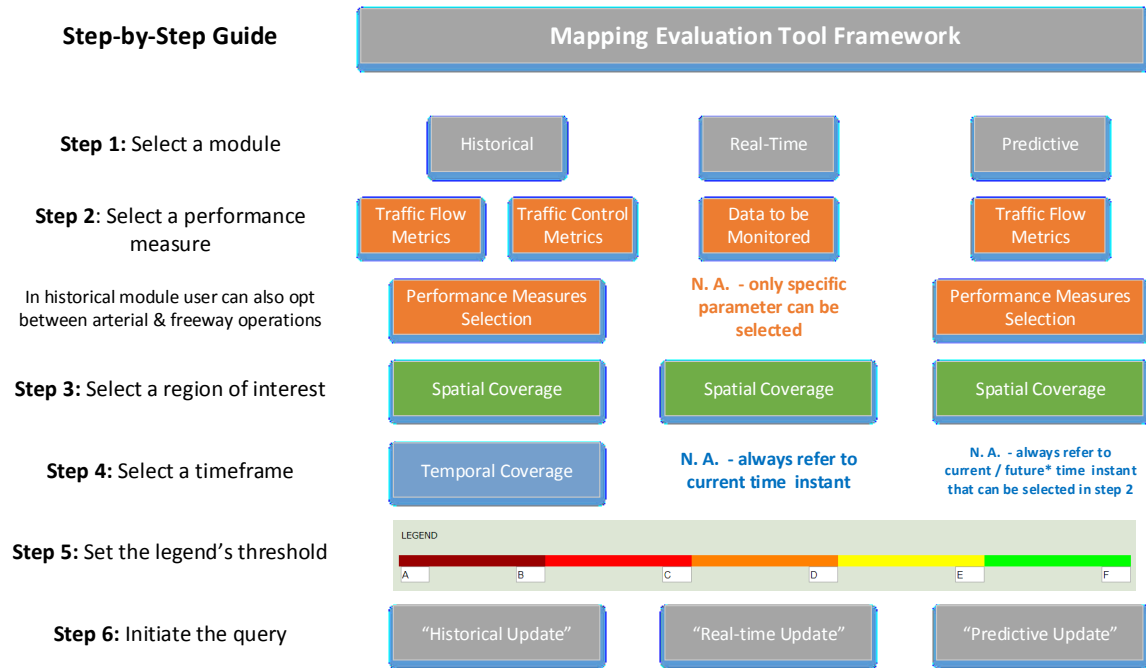


Figure 6-1: Step-by-Step Guidance for Setting Up the Query

This information can help users decide which module they want to use. The module is selected by clicking the radio button on the left side of the module that the user wants to select (see Figure 6-2). Noteworthy, a user can select only one module at the time.

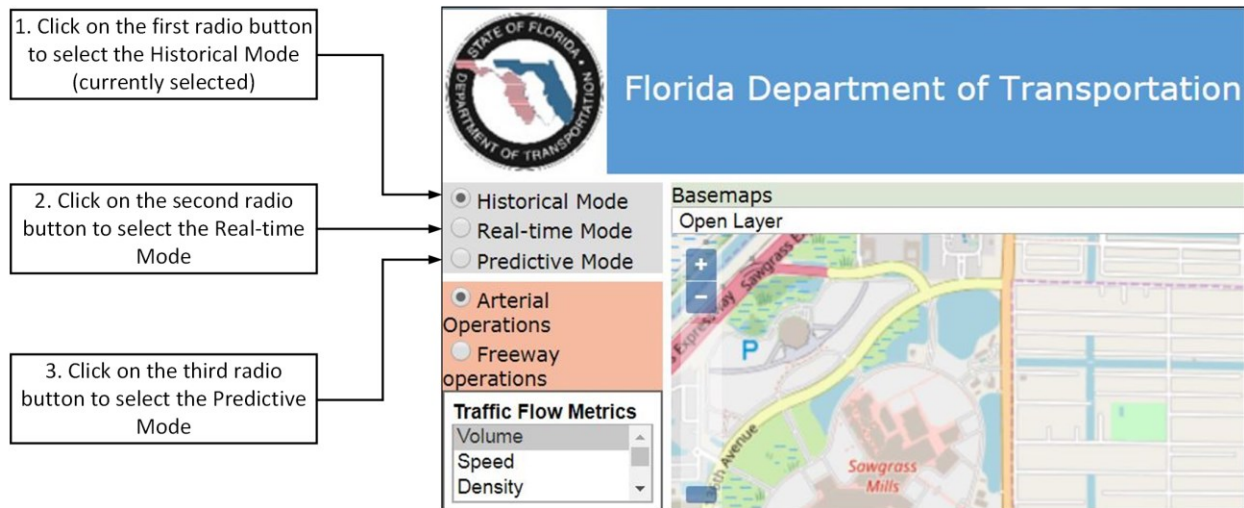


Figure 6-2: Mode Selection

6.3 Selection of Performance Measure

A tab with performance measures is given in orange color and placed immediately below the module tab (given in gray). Here, the user needs to select the performance measure that (s)he wants to investigate.

6.3.1 Performance Measures within the Historical Module

Since the focus of the MET tool is on monitoring the real-time information (within real-time module) and on spotting the unusual behavior (within the predictive module) the historical module is coded to allow the basic features. So far, the user can investigate volume and density historical data provided by FDOT (SunGuide) as well as speed, travel time and delay information provided by RITIS and HERE. All of these metrics are associated with *traffic flow metrics*.

Figure 6-3 shows how to set the performance measure within the historical module. The available performance measures, each measured in 15-minute time periods, are:

- **Volume** - This performance measure refers to the average one-directional 15-minute flow for selected stations within the predefined region and interval of time (a maximum of 10 days).
- **Average speed** – This performance measure represents average 15-minute speed for selected segments within the predefined region and interval of time (a maximum of 10 days).
- **Density** - This performance measure shows average 15-minute density at selected stations within the predefined region (discussed in Section 6.4) and interval of time (a maximum of 10 days).

- **Average travel-time** – This performance measure shows the average 15-minute travel time for selected segments within the predefined region (discussed in Section 6.4) interval of time (a maximum of 10 days).
- **Average delay** – This performance measure shows average delay for selected segments within the predefined region (discussed in Section 6.4) and interval of time (a maximum of 10 days), which is discussed in Section 6.5.

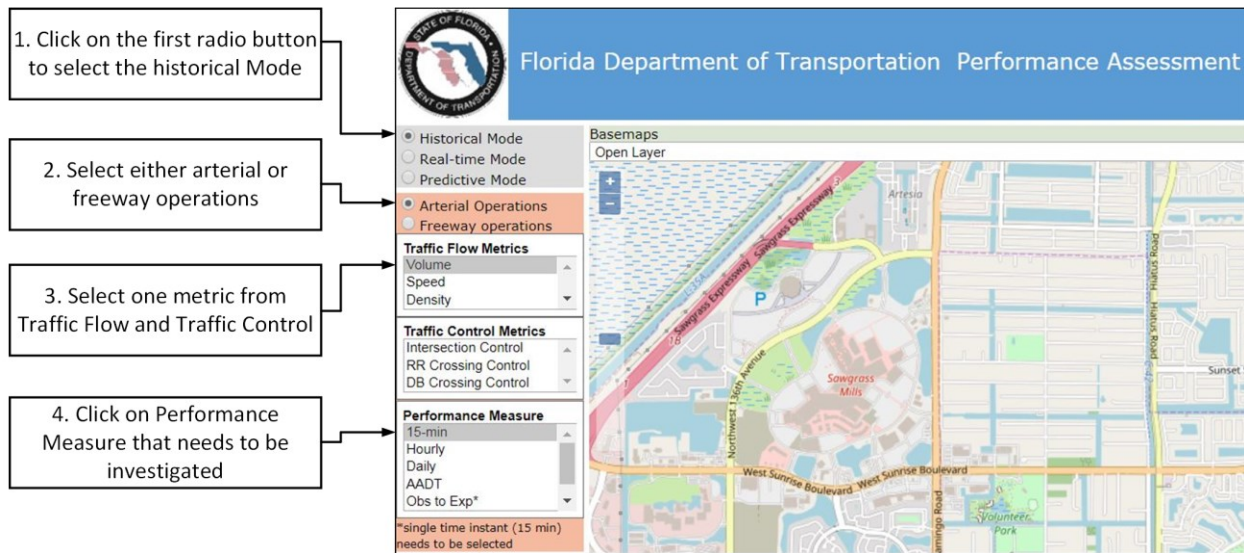


Figure 6-3: Selection of Performance Measure in Historical Module

6.3.2 Data to Be Monitored within the Real-Time Module

In the real-time module, the obtained real-time traffic information is presented on the map without any significant data-processing. Only in the context of traffic delay parameter the minor calculation needs to be performed; i.e., the delay is computed by subtracting the free-flow travel time of the corresponding segment from the reported travel time for that segment. The free flow travel time is defined as the minimum travel time recorded on a particular segment. Figure 6-4 shows the PostgreSQL code used to compute the free-flow travel time and subsequently delay (located in the /fdot_pams/database_schema/schema.sql file)

```

11 CREATE TABLE here.corridor_travel_data_minimum
12 AS (SELECT tmc, max(speed) as max_speed, min(tvtime_sec) as min_tvtime_sec FROM here.corridor_travel_data group by tmc);
13

```

Figure 6-4: Extracting the Minimum Travel Time that is Later Used for Delay Calculations

A user can select only one of the parameters from the list (see Figure 6-5) for which the real-time data exist. These parameters are volume and density (as points-based measurements provided by

SunGuide platform) and travel time, speed and delay (segment-based measurements provided by RITIS platform).

- **Volume** - the last available flow information will be presented on the map.
- **Density** - the most recent density information will be presented on the map.
- **Travel time** - aggregated (by HERE) in 1-2 minute bins and like that will be presented on the map. We refer to this as average travel time for the last 1-2 minutes. The missing values will not be imputed and hereby not presented on the map.
- **Speed** - provided by HERE every 1-2 minutes. We refer to this as average (or prevailing) speed for a particular segment. The missing values will not be imputed.
- **Delay** – first computed using the most recent travel-time information and free-flow travel time of each link. Then, estimated delay is presented on the map and we refer to this as an average delay during the most recent aggregation interval (e.g. 1-2 minutes).
- **Preemption status** will be always shown on the map. The red train symbol is posted on these railroad crossings where the preemption is activated while the blue train symbol is attached to these railroad crossings where the preemption is not currently activated. In the same way, the FAU research team presents the status of preemption at drawbridge crossings using red and blue ship symbols.

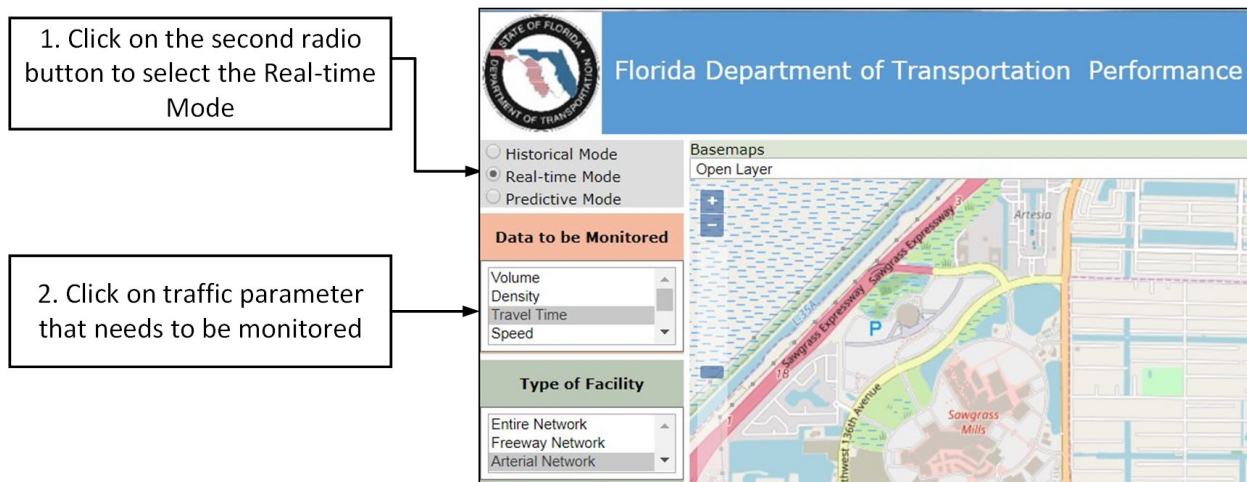


Figure 6-5: Selection of Performance Measures in a Real-time Module

6.3.3 Performance Measures within the Predictive Module

In the predictive module, the user first selects the traffic parameter (either volume or travel time) followed by the performance measure associated with the selected parameter. Figure 6-6 illustrates these steps.

Volume-based performance measures

- **Existing to Historical Volume (Obs - Exp* in the MET)** - This performance measure shows the difference between the recorded flow with its corresponding historical value for the same station and time instant. The negative values refer to these cases where the recorded value is higher than corresponding historical volume value. The negative values indicate that investigated facilities have less traffic than usual.
- **Existing to Historical Volume Ratio (Obs to Exp* in the MET)** - This performance measure shows the ratio between the recorded flow with its corresponding historical value for the same station and time instant. The common values of this performance measurements should be expected to be in the range of 0.75 – 1.25. The values higher than 1.0 indicate heavier traffic than usual.
- **Volume Percentile (Z-score* in the MET)** - This performance measure shows how many values (measured by percentage) observed at the same station and on the same day and time in the past are lower than the observed real-time flow. The common values of this measurements should be expected to be in the range of 30-70%. Unusual values are close to 0 (very low flow) or 100 (very high flow of vehicles).
- **Percent change in volume (Volume-reduction in the Met)** is calculated as $[(\text{expected volume} - \text{recorded volume}) / \text{expected volume}]$. Hence, if the expected (hist. average) volume is equal to the recorded (real-time) volume then the volume reduction will be 0. The negative volume reduction means that real-time volume is greater than the expected volume.
- **15-minute prediction** – is calculated as the mean value of expected and recorded volumes. 15-minute refers to the prediction horizon.

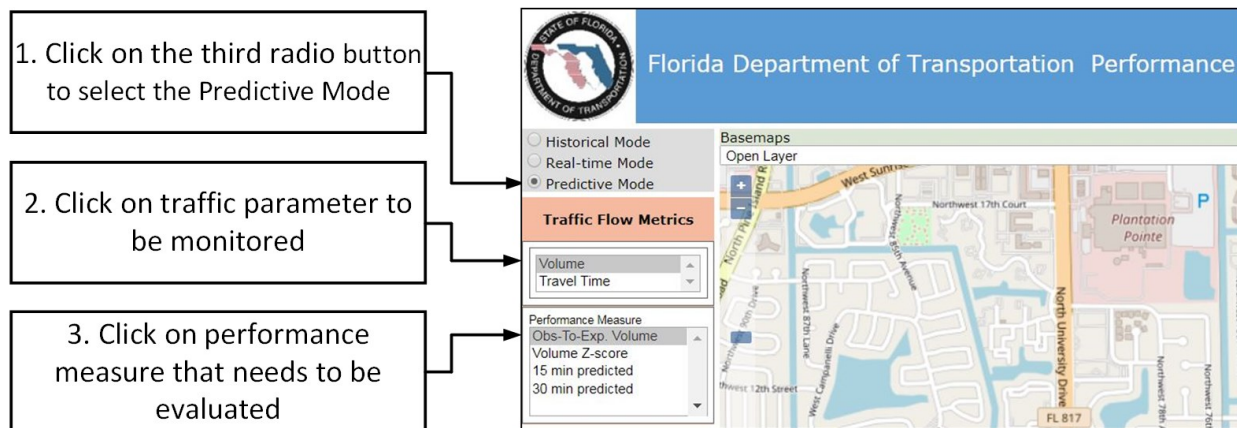


Figure 6-6: Selection of Performance Measure in Predictive Module

Travel-time-based performance measures

- **Delay** is estimated as a difference between the most recent travel time and travel time at free-flow conditions for the same segment.
- **Travel-time Index (TTI)** represents the ratio of the most recent travel time to the travel time at free-flow conditions.
- **Congestion level** is defined as a ratio between delay and free-flow travel time. In this way, if the prevailing speed is close to the free-flow speed and delay is close to zero then the congestion level will be also close to zero. Conversely, the significant delay would lead to the high congestion level.
- **Existing to Historical Delay*** shows the ratio between the recently observed travel-time and its corresponding historical value computed for the same segment and time instant. The common values of this performance measurement are expected to be in the range of 0.75 – 1.25. Values higher than 1.0 show that traffic is more congested than usual.
- **Existing to Historical Delay Ratio *** shows the difference between the recently observed travel-time and its corresponding historical value, computed for the same segment and time instant. A positive value indicates that the traffic is more congested than usual.
- **Travel Time Percentile (Z-score* in the MET) *** measure shows how many values (measured by percentage) observed in the same segment and on the same day and time instant in the past are lower than recently recorded travel time. This calculation is performed for each segment of the selected region and network. The common values of this performance measurements are in the range of 30-70%.
- **15-minute prediction** is calculated as the mean value of expected and recorded volumes

Speed-based performance measures

- **Existing to Historical Speed*** shows the ratio between the recently observed speed and its corresponding historical value, computed for the same segment and time instant (within a week). The common values of this measurement are expected to be in the range of 0.75 – 1.25. The values higher than 1.0 show that traffic is less congested than usual.
- **Existing to Historical Speed Ratio *** shows the difference between the recently observed speed and its corresponding historical value, computed for the same segment and time instant. A positive value indicates that the traffic is less congested than usual.
- **Speed Percentile (Z-score* in the MET) *** shows how many values (measured by percentage) observed in the same segment and on the same day and time instant in

the past are lower than recently recorded speed. This calculation is performed for each segment of the selected region and network. The common values of this measurement are expected to be in the range of 30-70%.

- **15-min prediction** is calculated as the mean value of expected and recorded speeds.

6.4 Region Selection

So far, the user has already defined the mode of investigated operations (given in gray tab) and the performance measure (given in orange tab). In this step, the users need to select the region where they want to analyze the selected performance measure. The selection of the region or “spatial coverage” is given in the green tab and placed below the (orange) performance measure tab.

In historical mode, the user can select from a single facility or station up to the entire network. The facilities can also be grouped according to major corridors in the network that they belong to and according to the direction that they are assigned to (see Figure 6-7). In the first step, the user needs to select the type of facility followed by a selection of the entities of the selected facilities. Secondly, the user needs to select the direction of the selected entities and facilities for which the data will be analyzed (see Figure 6-7). The default option refers to all directions.

1. Click on facility type that needs to be observed

2. Select a single or multiple facility for chosen facility type

Multiple entities can be selected by holding the “ctrl” key.

3. Click on the directions that need to be observed.

Multiple entities can be selected by holding the “ctrl” key.

Figure 6-7: Set the Spatial Coverage in Historical Module

In the real-time and predictive modules, the user has less flexibility in the selection of a region than in the historical module. Here the user can choose the entire network, which is a default option, freeway subnetwork, or arterial subnetwork (see Figure 6-8). Then, the user needs to opt

between a particular direction (or even all directions) for which the data will be analyzed. Similar to the historical module, the default option includes all directions.

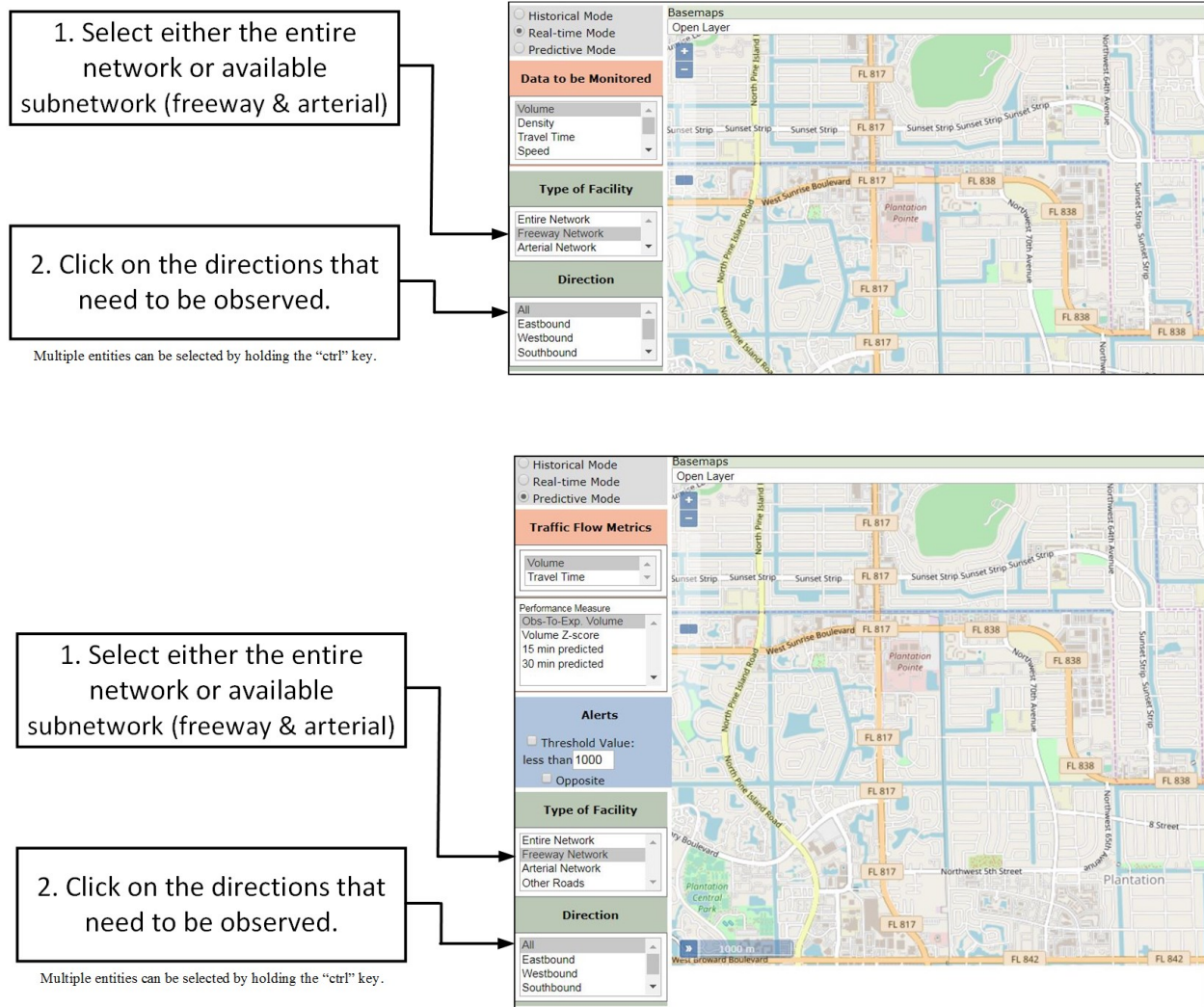


Figure 6-8: Set the Spatial Coverage in Real-time (*top*) and Predictive (*bottom*) Modules

6.5 Time Interval Selection

Time period selection is given in the blue tab and is applied to only the historical module. The real-time and predictive modules refer to the present time. For this reason, the selection of time period is omitted in the real-time and predictive modules.

In the historical module, the users first select the starting and ending dates, using the pop-up windows that allow day selection (see Figure 6-9). In this way, the users pick the time period for which they want to analyze the already selected performance measure. Then, the users can select

single or multiple days of the week for which the analysis will be performed (see Figure 6-9). The default option includes all days. After this step, the users need to choose the time of the day if they want to analyze any specific period of the day, shorter than 24 hours (see Figure 6-9). Otherwise, they can leave the “all” default option selected.

1. Select the first and the last day of analyzed period

2. Select a single or multiple days of the week for the analysis

Due to sheer volume of historical data maximum is 10 days

3. Select the start and end time of the investigated interval

Figure 6-9: Set the Time Period in Historical Module

6.6 Setting the Legend’s Thresholds

To visualize the selected performance measure on the underlying map, the FAU research team uses commonly applied the color-map method. The colored symbol is assigned to a particular

facility where the color is defined as a function of the numerical value of the performance measure associated with that facility. Usually, the dark red color is associated with the less preferable traffic conditions while the green color is referred to a smooth or desired traffic conditions, often associated with the high speed and low delay or travel time. One might see that the different performance measures (e.g., speed or travel time) might require the different orientation of the legend; for instance, in the *higher* speed, and *low* travel time values are associated with green color in the legend. In addition, some legends might have different ranges. For instance, while speed can be expected in the range 0-80 mph, the “Obs-to-Exp speed” that shows the ratio between experienced and historical speed is often in range 0.5 – 2. For all these reasons, the FAU research team makes an interactive legend and provides the user with the opportunity to adjust each range associated with a particular color. In this way, the FAU research team coded quite a robust legend that can be applied to all performance measures developed in this study.

Figure 6-10 depicts the logic behind the legend. It shows that dark red is associated with all values that are between **A** and **B** even if **A** is greater than **B**. In other words, the legend might be organized in a way that **B** (or **F**) is lesser than **A**. Noteworthy, letters A-F in Figure 6-10 refer to a numerical values and not to the Level of Service (LoS). Figure 6-11 shows some of the recommendations for the speed data (*top*), “*obs – exp. speed*¹⁹” (middle) and “*obs – exp. travel-time*²⁰” (bottom). Noteworthy, the minimum and maximum values in the legend need to be carefully defined to ensure that all feasible options will be presented on the map. This sort of legend can help the user easily spot the traffic parameter or performance measures that are within a particular/investigated range by assigning that range to a single color within a legend. We suggest users use this option to spot the irregular traffic behavior.

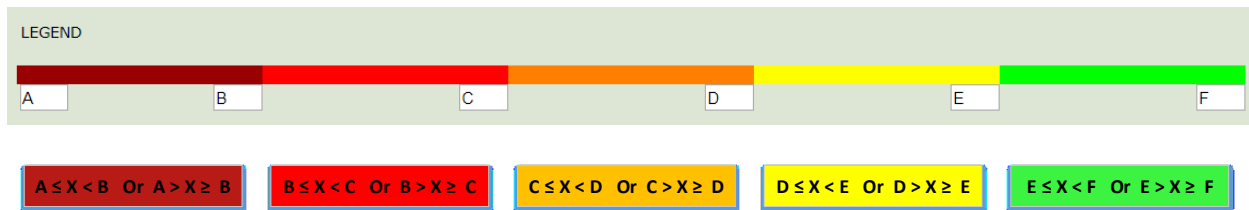


Figure 6-10: Legend Used within the MET Tool

¹⁹ Difference between observed (real-time) speed and historical speed for a particular segment and instance of time

²⁰ Difference between observed travel time and historical travel time for a particular segment and instance of time

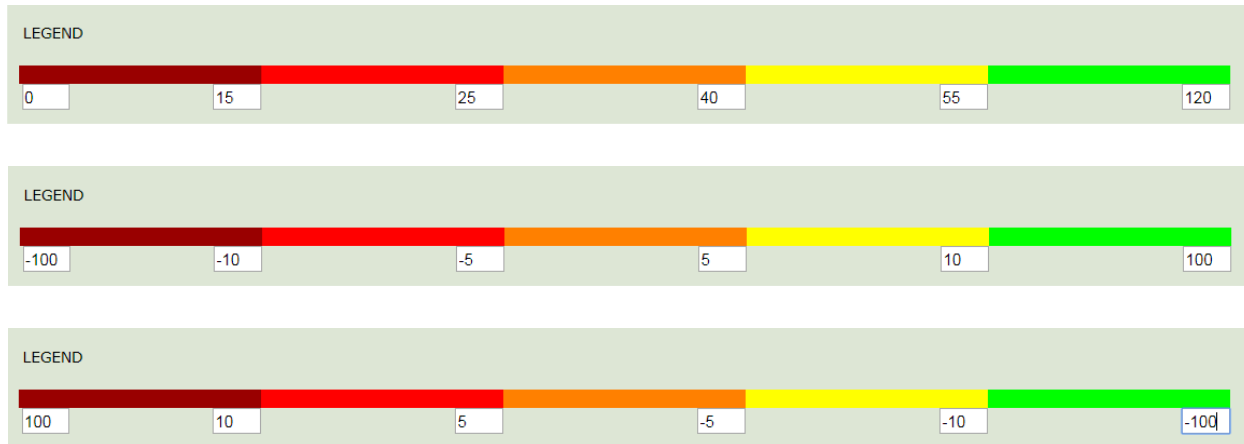


Figure 6-11: Setting Legend for Speed (*top*) and Travel-Time (*bottom*)

6.7 Query Initialization

Section 6.2 – Section 6.6 describe how to set the key components of a query: (i) module, (ii) performance measure, (iii) region, (iv) time period, and (v) legend. Once all components of the query are set, the user needs to generate that query by pressing the update button. If the query is properly set, the MET will start the analysis. Otherwise, the user will be informed that some of the selected parameters are not feasible or unrealistic (see Figure 6-12). Noteworthy, some queries might be computationally extensive and may require tens of seconds or even more for their completion.

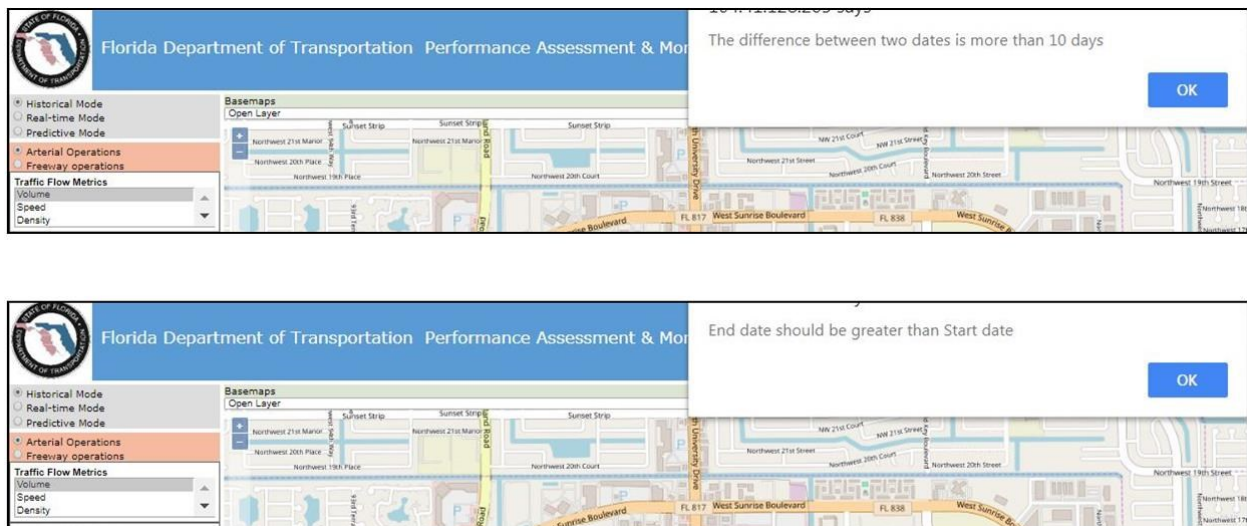


Figure 6-12: Pop-up messages for unfeasible (*top*) and unrealistic (*bottom*) queries.

6.8 Presenting the Query's Results

The results are presented on the map, in the form of basic statistics and in the form of graph representation. Figure 6-13 shows one instance of output results. In the context of the historical module, data can be presented in the form of line chart and box-plot graphs. In the context of the

real-time and predictive modules, the output of a query is given in the form of a single vector and thereby the results are presented in the form of a horizontal bar chart (see Figure 6-13).

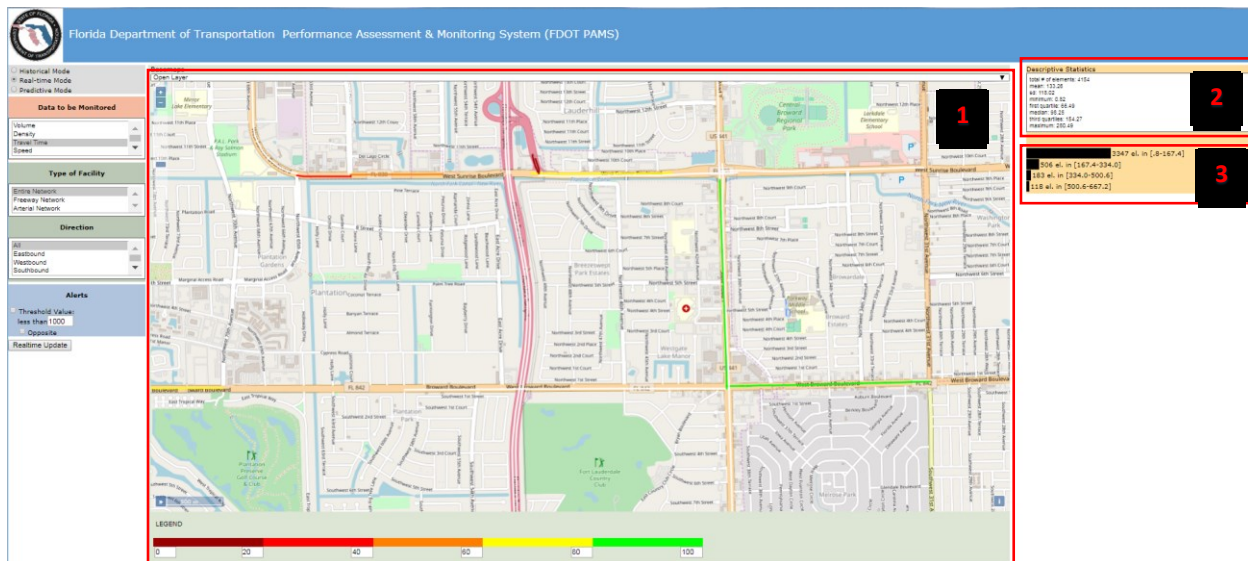


Figure 6-13: Forms of Query Results: (1) Map, (2) Common Statistics, and (3) Graph.

6.9 Use Cases

The Map Evaluation Tool can help the operator monitor the traffic conditions and spot irregular behavior. The tool is also capable of presenting the basic statistics and graphs to the operator pulling the historical information from the traffic databases. In following, the FAU research team presents the key features of the developed tool.

6.9.1 Use Case 1: Monitoring the Traffic Conditions

Let us assume that the operator is asked to monitor the speed in the network and spot the facilities whose speed is below 15 mph. Figure 6-14 shows how the MET tool should be set to perform this task.

Step 1: The operator needs to select the *real-time module* since the most-recent information needs to be analyzed. Operator selects *speed* as a traffic parameter of interest. Then, the operator selects the *entire network* and *all directions* since there are no temporal and spatial requirements imposed. These settings are shown in Figure 6-14 and denoted with number 1.

Step 2: To identify the facilities (segments) whose speed is below 15 mph, the operator needs to set the thresholds within the legend accordingly. The part of Figure 6-14, denoted with 2, shows an instance of how a legend can be set to color only facilities whose speed is between 0 and 15 mph in assigned color (in this case dark red).

Step 3: Once the operators set all required inputs (left side of the website and legend) they need to press the *update* button and allow some time for the program to construct and run the query and

visualize the data. In the context of real-time operations related to RITIS and HERE data, the total computation time is within a few seconds.

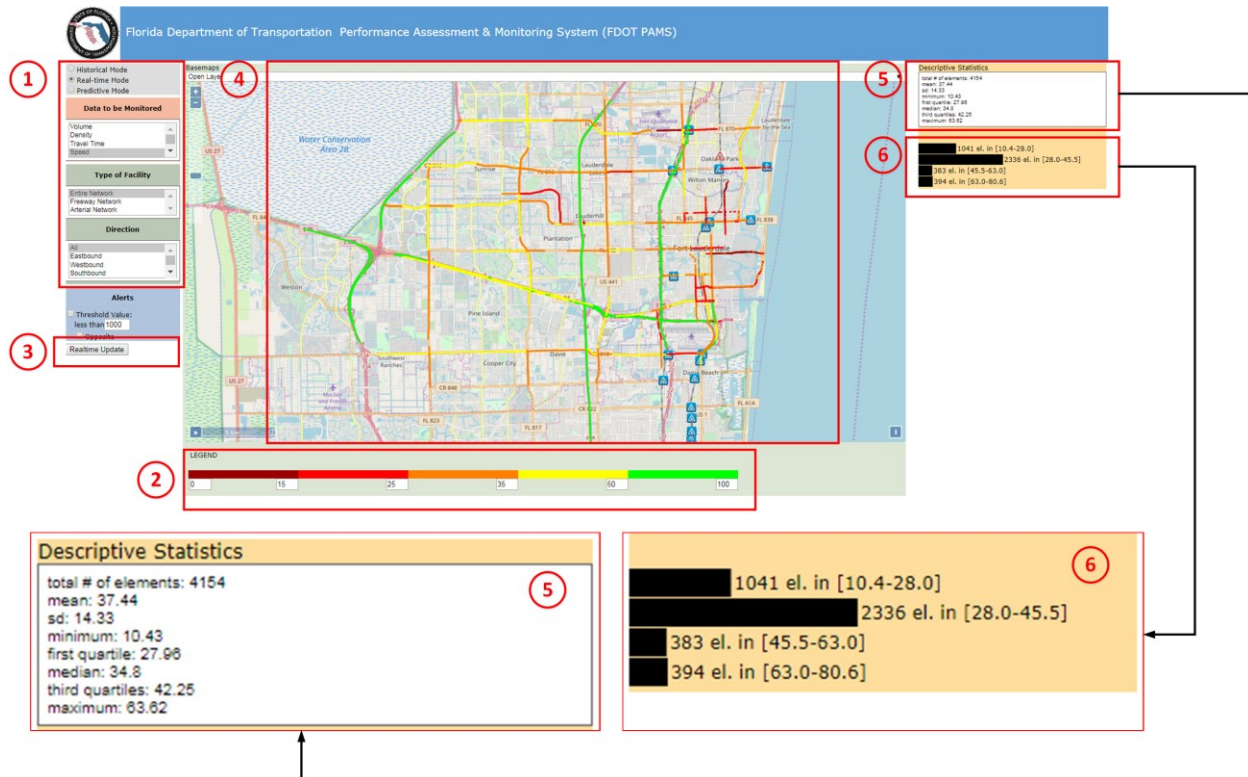


Figure 6-14: Monitoring Real-Time Speed data

Step 4: The output of the operator’s query (i.e. most recent speed data) is used to color the underlying network map. Facilities whose speed is between 0 and 15 mph are colored in the dark red color. From Figure 6-14, it can be seen that critical segments (with low speed) are located along E. Las Olas Blvd and along Commercial Blvd near the I-95 ramps. As expected, the Figure shows that facilities with high speed (associated with green and yellow colors) are located along the highways (I-95, I-595) and Turnpike. Noteworthy, some segments have no (most-recent speed) information, and no color has been assigned to these segments (e.g., in the vicinity of I-75 and I-595).

The activation of the railroad crossings and movable drawbridges, based on the most recent data, is depicted on the underlying map using the train- and drawbridge-based symbols, respectively.

Step 5: Major statistics are provided for the most recent speed information. These statistics show that it can be seen that the average network speed is 37.44 mph and the associated standard deviations is 14.33. The minimum reported speed is 10.43 mph and the maximum reported speed (once the outliers are removed) is 63.62 mph. The total number of facilities that have the most recent speed data is 4,154. Noteworthy, some of RITIS and HERE traffic message channels have

been divided into multiple adjacent links or facilities to better match and overlay with underlying network geometry.

Step 6: For a single time instance and multiple (4,154) facilities, the data is divided into four mutually exclusive groups and presented in the form of a bar graph. From this bar graph, it can be seen that 1,041 facilities have a speed lower than 28 mph, while 2,336 facilities in the network have a speed between 28 and 45.5 mph, and the trend continues.

In a similar fashion, the operator can monitor other traffic performance such as delay and travel time.

6.9.2 Use Case 2: Revealing the Unusual Traffic Conditions

The reported speed (presented in Section 6.9.1) depicts the current traffic conditions. To get more insightful information about the traffic performance in the network, one needs to match and link the reported speed with the speeds that can be expected, based on the provided historical information. In other words, the MET tool provides an option to the operators where they can explore the difference of the reported speed and the historical speed along the corresponding facility at the same time and on the same day. This is referred as the “Obs-Exp” (where observed = reported and expected = historical) performance measure within the predictive module. Figure 6-15 shows how the reported information complies with the relevant historical information for the same facility. From Figure 6-15, it can be seen that “critical” facilities along Las Olas Blvd, Commercial Blvd and Flamingo Road report speeds that are at least 5mph lower than the historical values for these facilities. The speeds at most facilities along I-95 are higher than the corresponding historical values (e.g., expected values).

The website layout is similar to one presented in section 6.9.1 and it contains: (1) the inputs that need to be provided by user; (2) a flexible legend; (3) an update button used to run the query; (4) a map window where the facilities are colored; (5) a statistics window and (6) a graph window (see Figure 6-15 for more details).

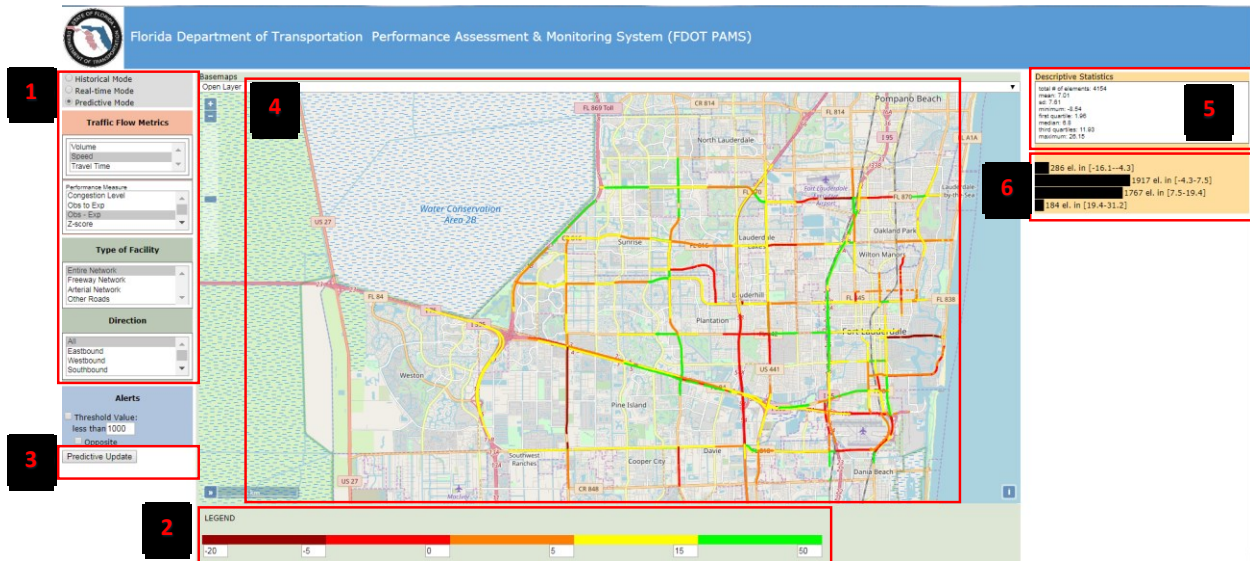


Figure 6-15: Obs – Exp Speed is Used to Spot Irregular Traffic Conditions

6.9.3 Use Case 3: Pulling the Historical Information

The MET tool offers not only the advanced features, which often cannot be found at the relevant traffic platforms (such as RITIS), but also the conventional options such as pulling the specific data from the historical databases. In this regard, the brief example is presented where the average speed is investigated for the single road, University Drive, during a particular time period, 7:30 AM – 9:15 PM on a single day, September 1, 2017. Figure 6-16 describes how an operator should define the input parameters and what (s)he can expect as the output of this analysis. First, only data for the facility of interest are presented on the map and follow the color code as it is defined (by operator) in the legend (see 4 in Figure 6-16). Second, only speed recorded at investigated facilities *and* during the period of interest are considered for computations of basic statistics (see 5 in Figure 6-16). Third, the values on the graph are presented only for the period of interest (see 6 in Figure 6-16).

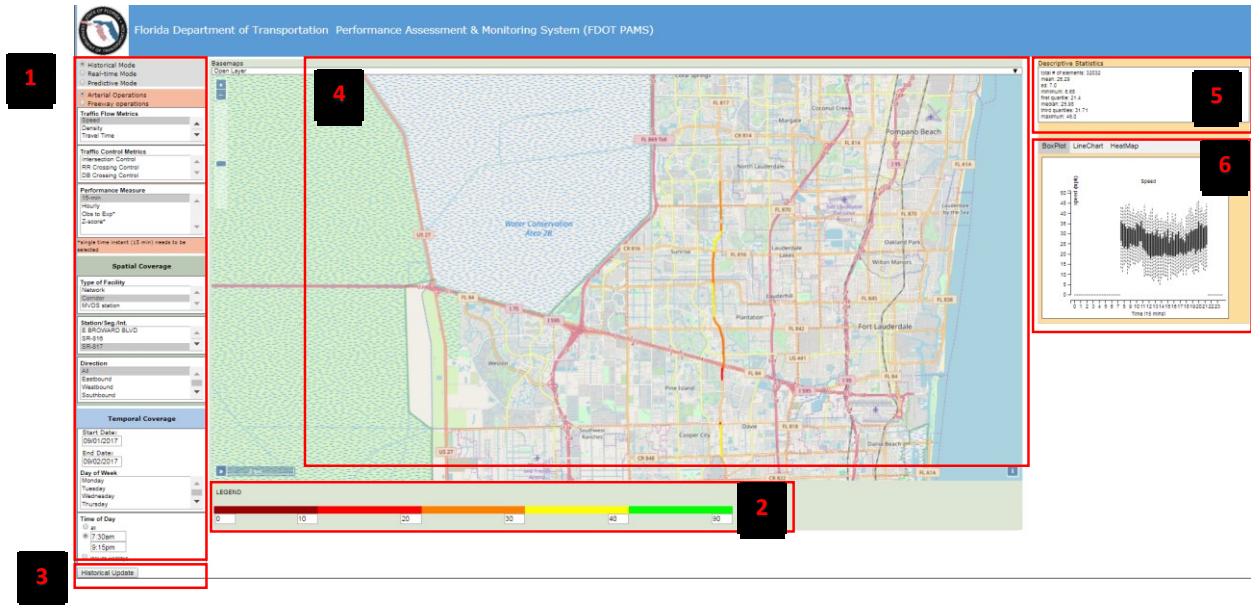


Figure 6-16: Pulling the Historical Speed Data

7. CONCLUSIONS AND RECOMMENDATIONS

In summary, this project has established a framework for the MET, developed MET structure (backend and frontend), populated such a structure with the relevant traffic data, and developed a set of new performance measures, which can help TMC operators to better manage traffic by identifying congested spots and facilities and time periods with questionable data records. To successfully complete these key research objectives following tasks were performed:

- One of the first steps of the FAU research team was to review the relevant traffic platforms. The conducted literature review revealed the key features and limitations of each of the analyzed traffic platforms. In this analysis, commonly deployed performance metrics and capabilities of the existing traffic platforms were covered.
- In the next step, the FAU research team described a mathematical formulation of the performance metrics proposed to be deployed within the MET. Some of these performance measures are widely deployed within the other existing platforms, whereas the others are original contributions designed to address specific needs of TMC operators.
- Then, the FAU research team has processed available raw traffic data and constructed the database. The GIS-database is constructed in such a way that all of the data can be mapped to a single underlying map. FAU research team successfully resolved many issues related to the use of big data. For instance, provided data were properly aggregated, filtered, and irregular data were taken out.
- The FAU research team developed a Beta version of the MET by integrating the proposed performance measures and established databases in a web-based environment. Advanced functionalities of the MET were coded in such a way to provide users enough flexibility to construct various queries while assuring smooth flow of all procedures. The MET has been accompanied with a manual that describes how to use the tool and interpret results.
- FAU research team improved the Beta version of the MET and installed it on a server. The database and scripts were successfully copied on the server and properly connected. Then, a version of the MET installed on the server was properly tested. Finally, scripts that continuously retrieve real-time data and populate the database were run on the server.
- Developed version of the MET is quite robust and can be expanded in many ways. Some of the recommendations for future improvements were listed throughout the study.

Overall conclusions for this research can be summarized as follows:

- The existing traffic platforms are often traveler-oriented with a limited set of functionalities for operators interested in system-wide traffic performance.
- Novel performance metrics such as observed-to-expected ratio are promising in revealing the trends and common patterns of facilities' operations during specific periods of time.
- The traffic data contain their own idiosyncrasies and anomalies that need to be carefully addressed during the data pre-processing stage.
- The delivered MET tool can be further expanded and improved in many directions.

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