

## Activity 3: Work Zone Mobility Monitoring Program

# Development and Implementation of WIMAP Application (I-295 Direct Connect Case Study)

### Final Report



Prepared for  
STATE OF NEW JERSEY  
Department of Transportation

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# **Development and Implementation of WIMAP Application (I-295 Direct Connect Case Study)**

## **FINAL REPORT**

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This report has been prepared as part of the CY 2015-2016 work program for the ITS Resource Center at the New Jersey Institute of Technology.

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# Executive Summary

With data being produced at an unprecedented rate, the use of visual data analytics for our transportation infrastructure is more crucial than ever to synthesize information, reduce cognitive work load, and derive insight for decision-making from analyzing massive and yet heterogeneous data. To fulfill such demand, the Work Zone Interactive Monitoring Application (WIMAP) was developed (Figure 1).

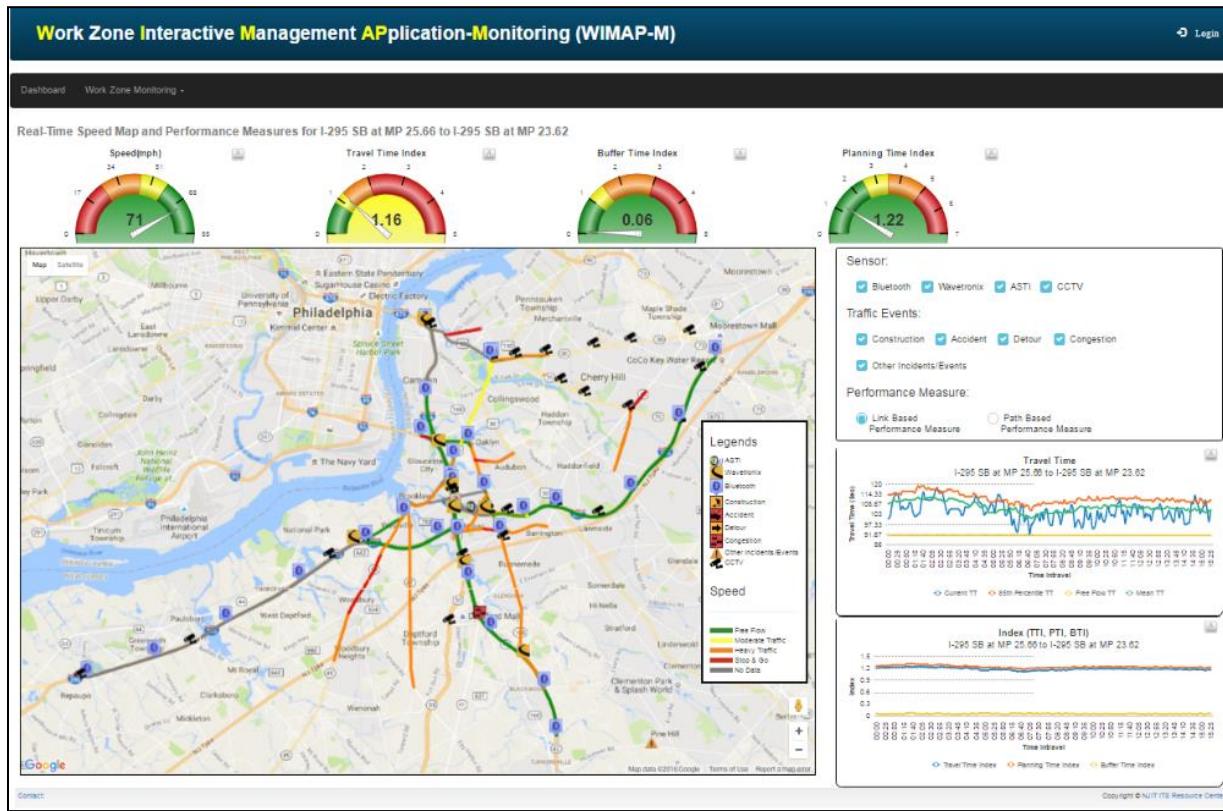


Figure 1. WIMAP Dashboard

WIMAP is a real-time, web-based roadway work zone management application catered to systematically monitor impact of I-295 Direction Connect reconstruction in New Jersey. WIMAP is designed to fuse heterogeneous data sources (e.g., remote traffic microwave sensors, Bluetooth sensors, OpenReach traffic incident data etc.) and provide users with instantaneous MAP-21 performance measure (e.g. travel time index (TTI), buffer index, planning time index (PTI), and percentile travel time, as well as formatted status reports. Additionally, its massive data retrieval engine, powered by high-end computational server, allows users to conveniently access the raw data of each data collection device for further exploratory date analytics.

This document aims to offer an overview of visual analytics of heterogeneous data sources for monitoring transportation infrastructure and work zone impact, and to suggest solutions for the challenges encountered during the process. Lastly, a separate 21-page WIMAP Quick Start Guide has been prepared to accompany both the web application and this report. Not only does the Guide demonstrate the application's ease-of-use for the general public, but it can also serve as an operational handbook for system operators.

# 1. Introduction

The Moving Ahead for Progress in the 21 Century Act (MAP-21), as the latest transportation fund authorization bill, requires every Metropolitan Planning Organization (MPO) to establish surface transportation performance targets. The spring of 2015 was chosen as the effective establishment date for all performance measures [3]. Six sets of performance measures were established by MAP-21, including national highway system (NHS) condition and performance, transit state of good repair, highway safety, transit safety, congestion mitigation, and air quality.

Work zone impacts are usually referred to as the deviation from the normal performance range of a given transportation network. It is estimated that work zone impacts constitute approximately 10% of overall congestion, which is equivalent to over \$700 million of value from fuel loss [4]. With the increased presence of work zones, it becomes critically important to monitor the work zone impacts so that suitable plans may be developed to improve mobility and safety.

Recently, NJDOT initiated the I-295 Direct Connection Project, a major highway interchange reconfiguration construction for I-295/I-76/NJ 42 in Camden County, New Jersey. The project commenced in March 2013, and it is expected to be completed in 2021. The project consists of four sequential construction stages assigned to different areas in the overall construction zone. During the project's development, a number of lane closures (both short-term and long-term) and traffic diversion strategies have been required and implemented. With the anticipation that the lane closure plans would have a significant impact on the saturated network, a real-time monitoring system was proposed to monitor traffic status, including diverted traffic flow, and to help gain readiness for emergency response activities.

Through a research partnership agreement with NJDOT, a web-based performance measure system entitled Work Zone Interactive Monitoring Application (WIMAP) was developed by the Intelligent Transportation System Resources Center (ITSRC) at the New Jersey Institute of Technology (NJIT). Unlike other software systems developed previously for similar studies, WIMAP is the first web-based performance monitoring system (WPMS) that specializes in monitoring work zone areas and in calculating instantaneous mobility measures, as proposed by MAP-21. The system is specifically tailored for the I-295 Direct Connect Project, and is expected to be expanded to monitor work zones throughout the state of New Jersey. WIMAP allows users to collect, archive, and analyze traffic data that supports investigations on the impacts (e.g. recurring & non-recurring congestion, incident, traffic pattern change, etc.) of the long-term work zone (i.e., I-295 Direct Connect).

This report summarizes the effort and the results of the New Jersey ATM screening process. The goal of this effort was to identify and prioritize an Active Traffic Management (ATM) deployment program for New Jersey Department of Transportation (NJDOT), including specific ATM strategies and roadway segments.

## 2. Development of Work Zone Monitoring

The web-based performance monitoring system (WPMS) is emerging as an intelligent transportation system and effective management tool for monitoring urban transportation networks, analyzing congestion, and providing better services to road users. The WPMS allows traffic operators, engineers, and planners to obtain real-time traffic information, such as current and historical traffic conditions. WPMS also facilitates the abilities of road users to better plan their journeys (e.g., route choice and departure time determination), which results in the alleviation of overall congestion and the achievement of higher network efficiency.

### 2.1. Literature Review

An extensive literature review was conducted to identify prior relevant studies. The major focus of the literature review was centered on web-based performance monitoring systems and performance measures. The research team identified the following four successful monitoring systems, which have been adopted and implemented by many public transportation agencies in the United States:

- ▶ ITERIS Performance Measurement System (iPeMS)
- ▶ Vehicle Probe Project Suite (VPP Suite)
- ▶ Performance Monitoring and Measurement System (PMMS) [7]
- ▶ Portland Oregon Regional Transportation Archive Listing (PORTAL) [8]

iPeMS [5] is a commercial software product that assists engineers and planners in monitoring highway mobility and in assessing the performance of freeway systems. iPeMS is currently used by various public transportation agencies (e.g., state DOTs, Harbor Department, regional transportation authorities, etc.) for the purposes of traffic operation and transportation planning. It was initially developed by the University of California at Berkeley in conjunction with Caltrans, and it has been commercialized and tailored to customer's specifications [9] (e.g., availability of data sources and desired performance measures). Caltrans PeMS, a variant of iPeMS, collects data from a variety of ITS sensors (e.g., loop detectors, radars, GPS-based probes, etc.) as well as existing online databases (e.g. Traffic Accident and Surveillance Analysis System, California Highway Patrol Incident Database, etc.) to display performance measures.

The VPP analysis suite [6], developed by the Center for Advanced Transportation Technology Laboratory (CATT Lab) at the University of Maryland, is a performance measures tool used for analyzing and presenting real-time traffic and archived operations data. The suite uses the vehicle probe data supplied by INRIX along with other data sources such as incidents, AADT volume

counts, and weather, etc. The suite includes a collection of data analysis, visualization, and retrieval tools. The VPP suite allows users to monitor real-time speed and bottleneck locations. It estimates travel time index (TTI), travel time reliability metrics, and queue measurement. VPP Suite is used by most state transportation agencies that are members of the I-95 Corridor Coalition.

PMMS [8] was developed by the Regional Transportation Commission (RTC) of Southern Nevada. It supports Traffic Management Center (TMC) in monitoring and controlling traffic in the Las Vegas metropolitan area. PMMS allows users to pull real-time and historical freeway performance information. PMMS builds on the storehouse of raw data automatically gathered by the ITS sensors that the Nevada Department of Transportation (NDOT) has deployed on its freeway network (e.g., I-15, US 95, and I-215) and incident-specific data which is reported by the Nevada Highway Patrol dispatchers [10].

PORTAL was developed by Portland State University in cooperation with Oregon DOT. PORTAL receives a live data stream from the 450 inductive loop detectors comprising the Portland area's Advanced Traffic Management System (ATMS). PORTAL is designated as the Portland region's official data archiving entity, consistent with the region's ITS Architecture, and is being expanded to include automated reports of key transportation system performance measures including, speed, lane occupancy, flow, vehicle miles traveled, vehicle hours traveled, travel time and delay. The data sources and performance measures of each system are summarized in Table 1.

## 2.2. Performance Measures

WPMS can calculate various mobility, reliability, and safety measures that describe traffic status on highways. The mobility measures, including speed, delay, queue, travel time, etc., are both measurable and straightforward variables used for reporting current conditions. The reliability measures capture the degree of predictability in the road users' travel time. The safety measure usually refers to the number of accidents and accident rates.

Speed is the intuitive performance measure when it comes to evaluating mobility, and it is used by multiple WPMSs. Spot speed (i.e., time of mean speed) collected by ITS device (e.g., RTMS) is an accurate representation of the speed of a vehicle crossing a certain spot. However, spot speed is not an effective measure in practices, especially when it comes to measuring speed over a long stretch of roadway. In that case, space mean speed is an appropriate measure that can be used for long segments of roadways. While space mean speed is the most easily-obtained speed, it often produces a statistical bias, particularly when applied to a long stretch of roadway [14]. This type of bias often occurs because space mean speed is more likely to suffer from the risk of overly homogenizing the speed of vehicles on a roadway.

Table 1. Summary of Existing WPMS

WPMS	Data Sources	Performance Measures		
		Mobility	Reliability	Other
VPP Suite	<ul style="list-style-type: none"> <li>• INRIX data</li> <li>• HPMS (AADT data) [11]</li> <li>• Loop detectors</li> <li>• Radars</li> <li>• Weather</li> <li>• Agencies data</li> </ul>	<ul style="list-style-type: none"> <li>• Speed</li> <li>• 95th percentile speed</li> </ul>	<ul style="list-style-type: none"> <li>• Travel time index (TTI)</li> <li>• Buffer Time index (BTI)</li> <li>• Planning time index (PTI)</li> </ul>	<ul style="list-style-type: none"> <li>• Throughput</li> <li>• Productivity</li> </ul>
iPeMS	<ul style="list-style-type: none"> <li>• Remote Traffic</li> <li>• Microwave Sensor</li> <li>• (RTMS)</li> <li>• WIM stations</li> <li>• GPS-based probes</li> <li>• Loop detectors</li> <li>• TASAS</li> <li>• CHP</li> <li>• Weather</li> </ul>	<ul style="list-style-type: none"> <li>• Speed</li> <li>• Queue</li> <li>• Delay</li> <li>• Occupancy</li> </ul>	<ul style="list-style-type: none"> <li>• Travel Time Index (TTI)</li> <li>• Buffer Time Index (BTI)</li> </ul>	<ul style="list-style-type: none"> <li>• Accident</li> <li>• Lost productivity</li> <li>• VHT</li> <li>• VMT</li> </ul>
PMMS	<ul style="list-style-type: none"> <li>• RTMS</li> <li>• Loop detector</li> <li>• Bluetooth reader</li> <li>• NHP</li> <li>• CCTV Cameras</li> <li>• Weather</li> </ul>	<ul style="list-style-type: none"> <li>• Daily average peak hours speed</li> <li>• Hourly average speed</li> <li>• Overall freeway average speed</li> <li>• Congestion</li> </ul>	N/A	N/A
PORTAL	<ul style="list-style-type: none"> <li>• In-house incident database</li> <li>• Loop detectors</li> <li>• TriMet vehicle information data[12]</li> <li>• METAR weather data[13]</li> </ul>	<ul style="list-style-type: none"> <li>• 15-min average speed</li> <li>• 5-min delay</li> <li>• 5-min travel time</li> <li>• 95th percentile travel time</li> <li>• Congestion frequency</li> <li>• VHT</li> <li>• VMT</li> </ul>	N/A	N/A

To avoid biased estimations, 15<sup>th</sup> percentile, 85<sup>th</sup> percentile, and 95<sup>th</sup> percentile speeds are often used along with space mean speed to preserve the fidelity of the population. It is worth noting that the 95<sup>th</sup> percentile travel time is employed to measure the delay for a specific roadway during the heaviest traffic days. It is also used as the worst day traveling indicator on a particular roadway in a certain month. PMMS plots the 15<sup>th</sup> percentile and 85<sup>th</sup> percentile speeds, which are then applied to demonstrate the predominant speed range. PORTAL uses 15-min average speed as one of the mobility performance measures, and displays it in the real-time speed map view. VPP Suite provides both mean speed and 95<sup>th</sup> percentile speed, while iPeMS only uses mean speed.

Travel time is another straightforward mobility performance measure for travelers. More than likely, travelers are expected to make their route choices based on estimated travel time. However, average travel time sometimes misleads road users, especially in congested networks during peak periods. Aiming to promote a performance measure which provides more accurate and practical information, MAP-21 proposes the use of travel time index, buffer time index, and planning index to represent the network performance capacity. These measurements are the most effective methods used to measure travel time reliability [15].

*Travel time index (TTI)* is a comparison between the travel conditions in the peak period to that of free-flow conditions. It uses the units of travel rate, due to the data elements and the ease of mathematical calculation. The TTI might also use direct travel time comparisons for trips of the same length. *Buffer time index (BTI)* represents the extra time that must be considered in order to ensure an on-time arrival at a traveler's destination. *Planning time index (PTI)* is the total time that a traveler should plan to ensure an on-time arrival, and is expressed as a ratio of the planned total travel time and the free-flow travel time of a particular roadway. Additionally, it is observed that an increasing number of agencies throughout the country have adopted the travel time reliability indices, including the Federal Highway Administration, Minnesota DOT, and the Washington State DOT. A study conducted by MN/DOT indicated that using travel time reliability indices, instead of average travel time, gained operational improvements [15]. Figure 2 is a demonstration of the relationship between PTI and BTI.

Congestion, as opposed to mobility, is also commonly used to measure or quantify the congestion in the network. iPeMS provides an algorithm used to calculate delay based on user-defined reference speed. iPeMS also provides queue measurement which is the ratio of Vehicle Miles Traveled (VMT) and Vehicle Hours Traveled (VHT): queue measurement can be computed both in single points as well as over many different links.

PMMS adopted a pre-defined set of four speed categories to classify congestions. PORTAL uses congestion frequency as an indicator of congestion. In addition to traditional performance measures, the concept of productivity was introduced as a new performance measure.

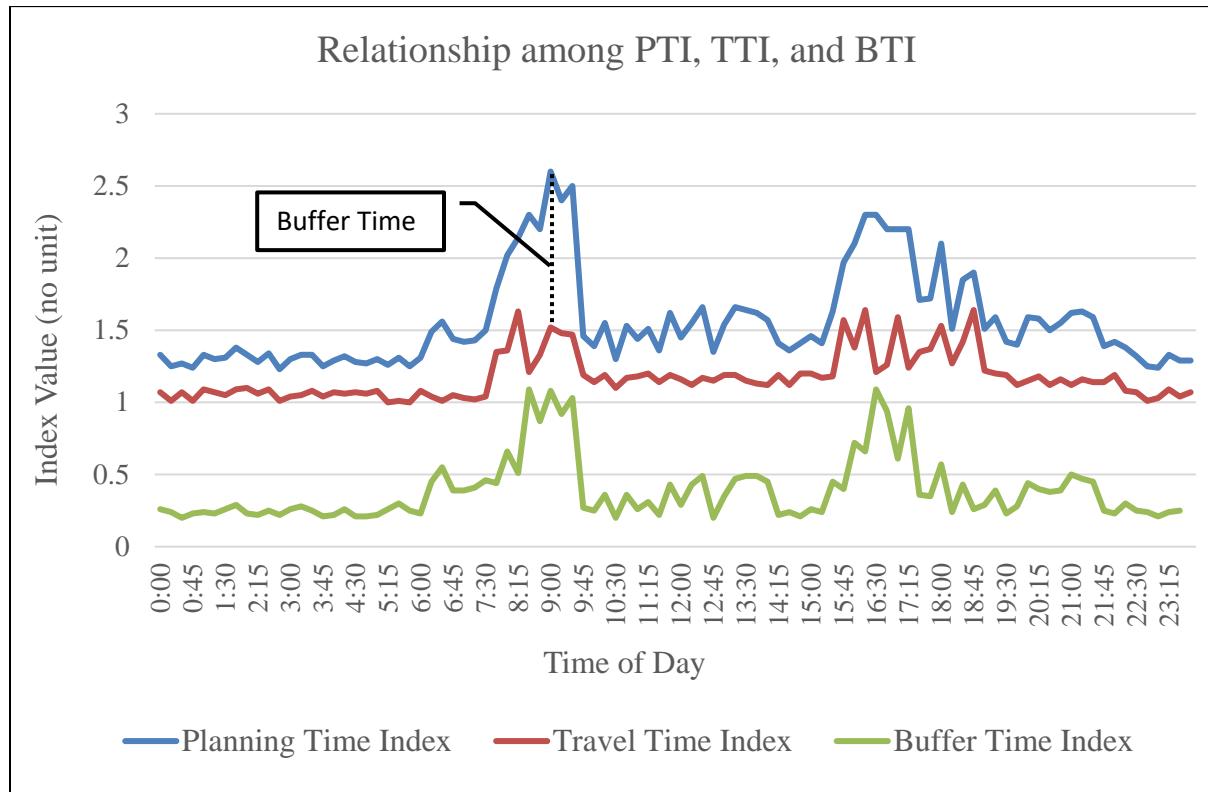


Figure 2. Travel Time Reliability Measures (synthesized data)

As a safety performance measure, iPeMS displays real-time accident information on the live traffic map by scraping data from the Traffic Accident and Surveillance Analysis System (TASAS) [16] and the California Highway Patrol (CHP) database. PMMS obtains incident data from the Traffic Incident Management Coalition (TIMC) through an agreement between the Nevada DOT and Nevada Highway Patrol. PORTAL and VPP suite provides the number of crashes and crash locations provided by the state 511 systems.

It is expected that many other new WPMSSs will emerge to monitor real-time traffic conditions and to reduce the cost of ITS devices. Currently, many WPMSSs provide user-friendly interfaces and enhanced visual presentations to display and collect real-time traffic conditions of freeway networks.

There is, however, no other system available which provides a dedicated platform for monitoring long-term work zone areas and their potential impacts on traffic. Consequently, WIMAP was developed to illustrate the real-time work zone monitoring practices nationwide.

## 2.3. WIMAP System Architecture

The system architecture of WIMAP is shown in Figure 3. WIMAP possesses dedicated high-end servers for rapid database management and handling of the on-line applications. WIMAP collects data from multiple sources and transmits the information to the database server housed in NJIT. As a WPMS, WIMAP allows users to access the collected data using the web applications. Upon a user's request, the application server retrieves data and performs the appropriate computations. A comparison of WIMAP functionality with that of the reviewed WPMSs is shown in

**Table 2**

Table 2. Comparison of WIMAP and Other WPMSs

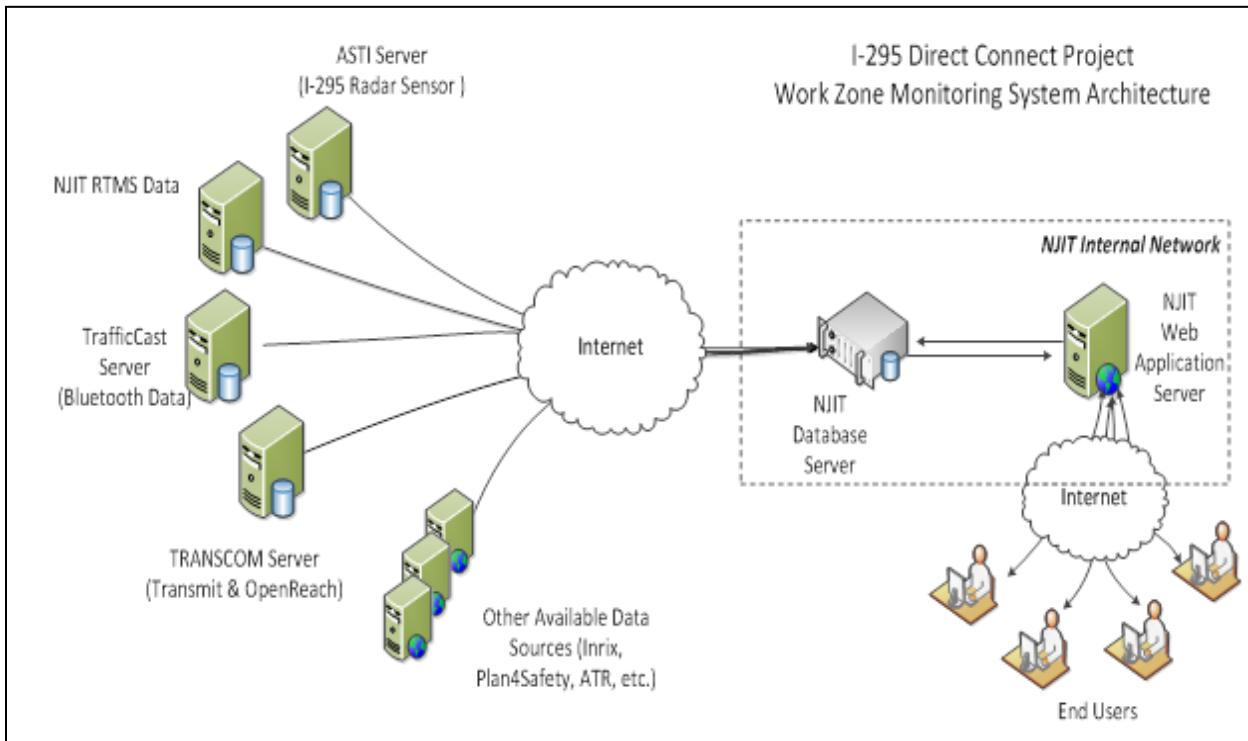


Figure 3. WIMAP System Architecture

Table 2. Comparison of WIMAP and Other WPMSSs

WPMS	Performance Measure	WIMAP	iPeMS <sup>1</sup>	VPP Suite	PORTAL	PMMS
Mobility Performance Measure	Real-time Speed	✓	✓	✓	✓	✓
	Real-time Travel Time	✓	✓	✓	✓	
	Real-time Traffic Volume	✓	✓		✓	
	Real-time Congestion Measure	✓	✓	✓		✓
	Spot Level of Service Index	✓				
	Recurrent Congestion Detection	✓	✓	✓		✓
	Delay		✓			
	Throughput			✓		
	Map-based Network Speed Comparison	✓			✓	
MAP-21 Performance Measure	Travel Time Index	✓	✓	✓		
	Planning Time Index	✓		✓		
	Buffer Time Index	✓	✓	✓		
Safety Performance Measure	Historical Accident Data	✓	✓	✓		✓
	Traffic Incident Data	✓	✓	✓		✓
Construction Activity	Lane Closure Activity Data	✓	✓			
	Variable Message Sign	✓	✓			✓
Other Data Sources	Transit Data	✓	✓		✓	
	Weather			✓	✓	
	Live Traffic Camera	✓				✓

1: Based on Caltrans iPeMS

## 2.4. WIMAP Data Sources

One of the key features of WIMAP is the integration of multiple data sources that are utilized to calculate various performance measures. WIMAP analyzes real-time and historical traffic flow

data that is continuously being collected and archived in a database server. The primary data sources of WIMAP include:

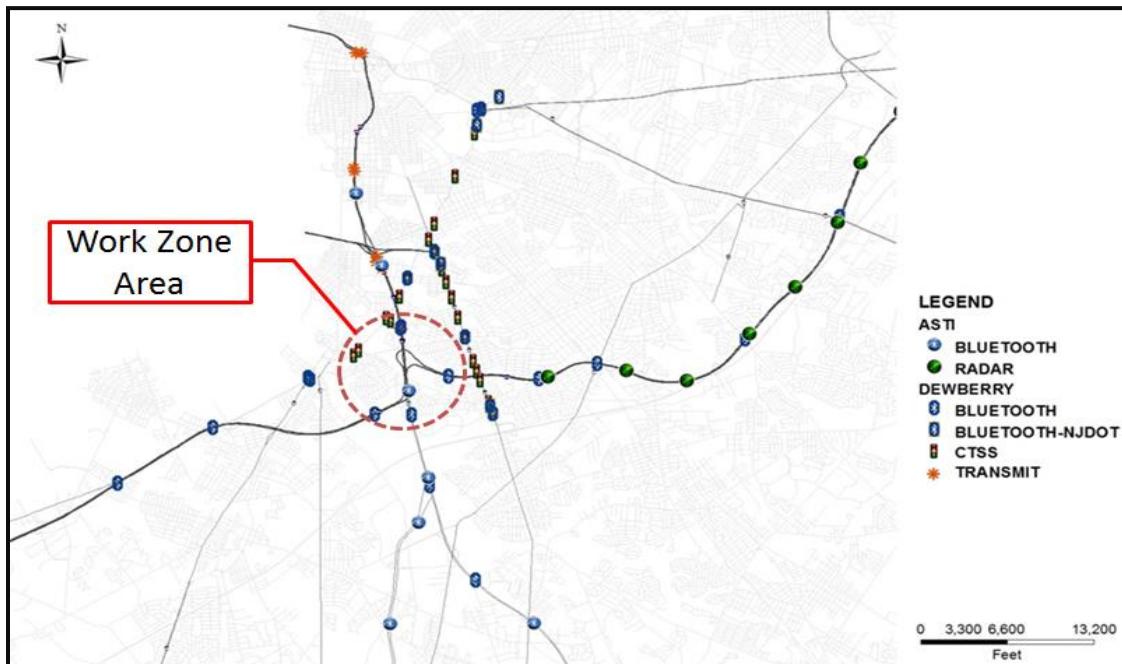
- ▶ RTMS devices
- ▶ Bluetooth sensors
- ▶ TRANSMIT readers (e.g., Electronic Toll Tag readers)
- ▶ Variable Message Sign (VMS)
- ▶ OpenReach (i.e., incident events database)
- ▶ Plan4Safety (i.e., accident and crash database)

#### 2.4.1. Field Devices for Data Collection

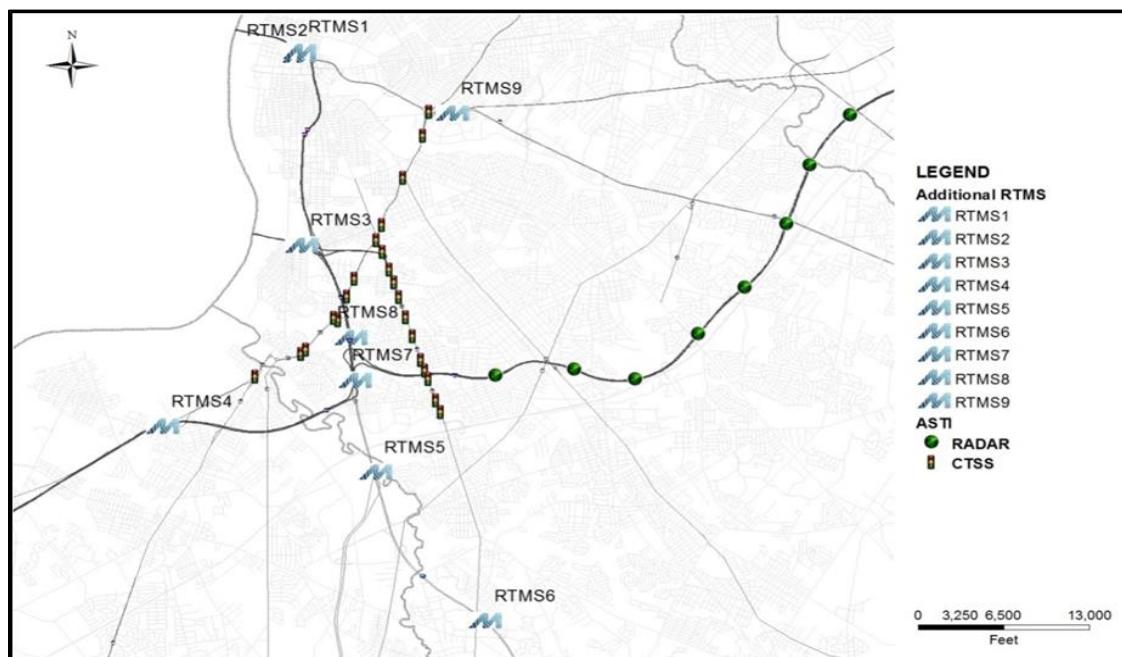
Nine RTMS devices (i.e., Wavetronix SmartSensor HD [17]) were instrumented around the I-295 Direct Connect work zone area. RTMS is the system of non-traffic-disruptive traffic flow monitoring sensors and is typically deployed on roadway overhead structures (e.g., light pole, gantry, portable trailer, etc.). RTMS emits microwaves intermittently to capture real-time traffic flow information, such as traffic counts, spot speed, and lane occupancy. The locations of the deployed and the proposed RTMS devices are shown in Figure 4 (b). Total of 9 RTMSs provides sufficient coverage for the overall work zone area.

Bluetooth is a global standard protocol suitable for mid- to short-range wireless communications between two mobile devices (e.g., laptop, smartphone, or tablet PC). One of the unique features of Bluetooth is the ability to sense the identification of those devices by capturing their Medium Access Control (MAC) addresses without a data authentication procedure. Travel time can then be calculated by matching a MAC address that is detected by a pair of Bluetooth readers at different locations. In addition, route travel and route diversion can be estimated by pairing two different readers. Currently, 41 Bluetooth devices are already installed or planned to be installed in and around the work zone, in a process being deployed and managed by TrafficCast. It is important to note that the reported MAC address matching rate found by BlueTOAD™ is approximately 4% of a daily traffic volume [18].

TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT), based on traffic probe vehicles which are equipped with the E-Z Pass electronic toll collection tags, is a traffic surveillance and incident detection system. TRANSMIT provides more reliable travel time information than conventional inductive loop detectors or image detection systems. WIMAP collects information from ten TRANSMIT readers that are in operation in the proximity of the work zone. TRANSMIT provides high-fidelity travel time information for those segments not covered by Bluetooth readers.



(a) Existing Data Collection Device (Bluetooth, Radars, CTSS, TRANSMIT readers)



(b) Instrumented RTMS Devices (RTMS 1 through 9)

Figure 4. Locations of Data Collection Device

Variable Message Sign is an electronic traffic sign technology that is used to provide special event information to travelers (e.g. warning of work zones, traffic congestion, accidents). Messages displayed in VMSs from around the work zone have been collected and archived. With such

information, WIMAP users are capable of investigating the relationship between traffic patterns and the messages in VMSs.

Centralized Traffic Signal System (CTSS) and Adaptive Traffic Control System (ATCS) to be installed on local highways around I-295 (e.g., US 130 and NJ 168) will be also integrated into WIMAP in order to display traffic counts on alternative routes. Table 3 summarizes the type and number of data collection devices.

Table 3. Number of Data Collection Devices

Device Type	Number of Devices
Bluetooth	41
RTMS (ASTI)	12
RTMS (Wavetronix)	9
TRANSMIT	10
CTSS/ASCT	23

In addition to the field devices, WIMAP also integrates OpenReach and Plan4Safety data to monitor and review work zone activities (e.g., lane closure, traffic mitigation plan, construction activities) and roadway incidents (e.g., crash, accident, and property damage). OpenReach is a web-based regional inter-agency network that provides information regarding all roadway incident events. Plan4Safety is a decision support tool that archives and store historical crash data from accidents that occur on New Jersey roadways.

## 2.5. Field Data Processing

This section describes the processing of real-time traffic status data collected by Bluetooth sensors and RTMS devices. The overall goal of this section is to explain the data processing procedures in WIMAP and the definition of performance measures associated with computational methods.

### 2.5.1. Data Process Work Flow

As illustrated in Figure 5, data processing begins with filtering data collected by Bluetooth sensors and RTMS (i.e., Wavetronix) devices that are installed in work zone areas. With data collected by the Bluetooth sensors, WIMAP computes (1) 95<sup>th</sup> and 85<sup>th</sup> percentile travel time, (2) free flow travel time, and (3) average travel time, which are then utilized to calculate reliability indices (i.e.,

TTI, BTI, and PTI). Meanwhile, WIMAP also processes data obtained from the RTMS devices to display real-time traffic volume, spot speed, volume over capacity (v/c) ratio, and level of service (LOS).

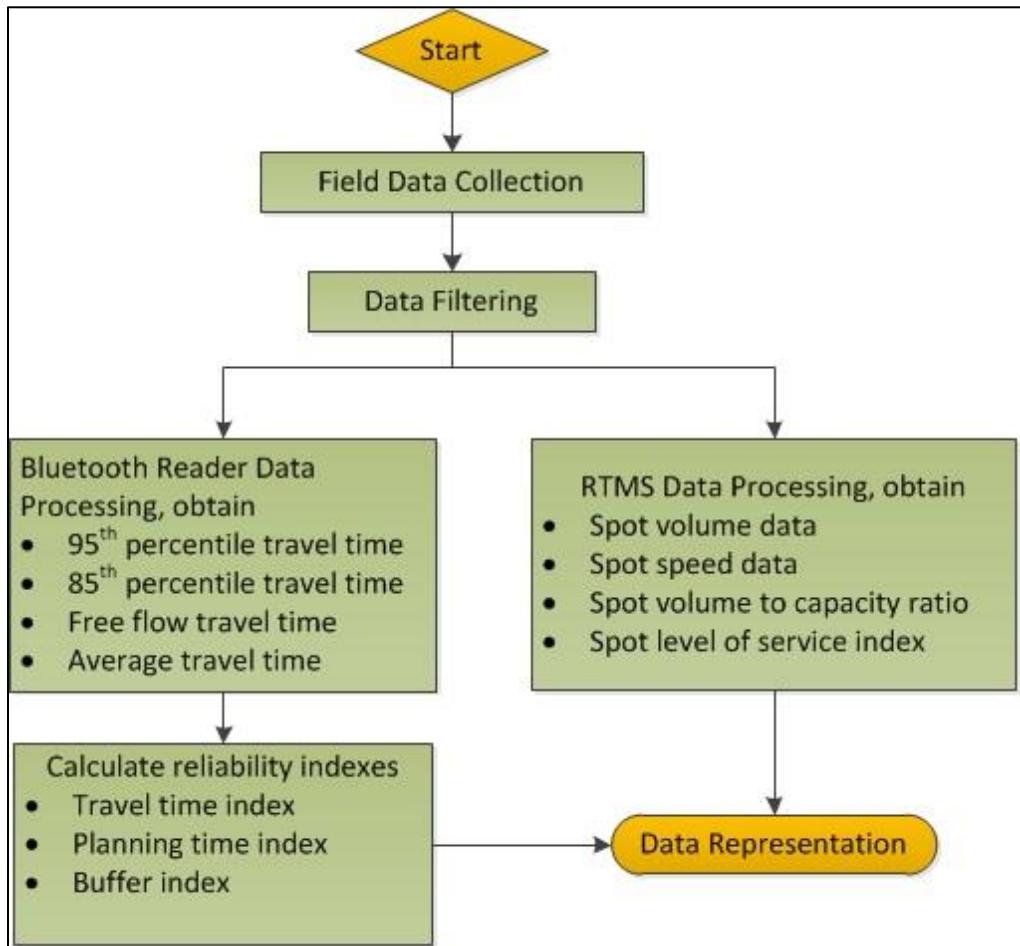


Figure 5. Data Process Flow Chart

### 2.5.2. Performance Measures and Calculations

Using the filtered data, WIMAP computes various performance measures as summarized in Table 4 and Table 5.

Table 4. Bluetooth-based performance measure

Performance Measures	Definition																					
<b>95<sup>th</sup>and 85<sup>th</sup> Percentile Travel Time</b>	<p>The travel time at or below 95 or 85 percent of a sample of vehicle travel time; this can be calculated by ranking the sample data pool of travel times in ascending order and then locating the value in the ranked travel time that is higher than 95 or 85 percent of the travel time, as shown below:</p> <table border="1"> <thead> <tr> <th>Travel Time (min) Collected for a Segment</th><th>Percentile Ranking (descending Order)</th></tr> </thead> <tbody> <tr><td>45</td><td>100%</td></tr> <tr><td>45</td><td>95%</td></tr> <tr><td>44</td><td>90%</td></tr> <tr><td>44</td><td>85%</td></tr> <tr><td>43</td><td>80%</td></tr> <tr><td>42</td><td>75%</td></tr> <tr><td>42</td><td>70%</td></tr> <tr><td>42</td><td>65%</td></tr> <tr><td>40</td><td>60%</td></tr> </tbody> </table> <div style="border: 1px solid red; padding: 5px; margin-left: 20px;"> <p>95<sup>th</sup> Percentile Travel Time: <b>45 minute</b></p> <p>85<sup>th</sup> Percentile Travel Time: <b>44 minute</b></p> </div>		Travel Time (min) Collected for a Segment	Percentile Ranking (descending Order)	45	100%	45	95%	44	90%	44	85%	43	80%	42	75%	42	70%	42	65%	40	60%
Travel Time (min) Collected for a Segment	Percentile Ranking (descending Order)																					
45	100%																					
45	95%																					
44	90%																					
44	85%																					
43	80%																					
42	75%																					
42	70%																					
42	65%																					
40	60%																					
<b>Free Flow Travel Time</b>	Travel time measured during free-flow traffic condition																					
<b>Average Travel Time</b>	Mean travel time during an observation period																					
<b>Travel Time Index</b>	<p>The ratio of average travel time and free-flow travel time:</p> $\text{Travel Time Index} = \frac{\text{average travel time}}{\text{free - flow travel time}}$																					
<b>Planning Time Index</b>	<p>Total time that a traveler should plan to ensure on-time arrival, expressed as a ratio of the planned total travel time and the free-flow travel time of particular roadway:</p> $\text{Planning Time Index} = \frac{\text{95th percentile travel time}}{\text{free - flow travel time}}$																					
<b>Buffer Time Index</b>	<p>The extra time that must be considered in order to ensure an on-time arrival at traveler's destination:</p> $\text{Buffer Time Index} = \text{Planning Time Index} - \text{Travel Time Index}$																					

Table 5. RTMS-based performance measure

Performance Measures	Definition 2
Speed	Spot speed (mph)
Volume	Number of vehicles passing a particular point on a roadway segment per hour, vehicle per hour (vph)
V/C Ratio	The ratio of measured spot volume and roadway segment capacity
Level of Service (LOS)	<p>A qualitative measure adapted to represent the service quality of a roadway segment. LOS is computed as follows:</p> <ol style="list-style-type: none"> <li>1. Calculate the free-flow speed of the selected roadway segment (unit: mph)</li> <li>2. Calculate the traffic flow rate of the selected roadway segment (unit: pcphpl)</li> <li>3. Calculate the density of the traffic flow based on flow rate and free-flow speed (unit: pc/mi/ln)</li> </ol> <p>Look up the level of service index in the speed-flow curves</p>

An example of how to calculate reliability indices, including TTI, PTI, and BTI is shown below:

#### Example

Assume that there is a roadway segment which has 15-minute free-flow travel time, 18-minute measured average travel time, and 25-minutes 95th percentile travel time. Then, the TTI, PTI, and BTI can be calculated as follows:

$$\text{Travel Time Index} = \frac{\text{average travel time}}{\text{free - flow travel time}} = \frac{18}{15} = 1.2$$

$$\text{Planning Time Index} = \frac{\text{95th percentile travel time}}{\text{free - flow travel time}} = \frac{25}{15} = 1.67$$

$$\text{Buffer Time Index} = \text{Planning Time index} - \text{Travel Time Index} = 1.67 - 1.2 = 0.47$$

## 2.7. WIMAP Components

In this section, the major components of WIMA, including interface and key functionalities, are introduced.

### 2.7.1. Dashboard

The WIMAP main dashboard provides charts and graphs, as shown in Figure 6. This intuitive web-based interface serves as a portal which allows users to retrieve and display real-time and historical traffic information. Users can choose the instrumented roadway segments of interest by clicking on their selection, and then the available performance measures are displayed in the dashboard. The WIMAP main dashboard was developed using Microsoft's Visual Studio 2012, Microsoft ASP.Net, Google Maps, and Google Charts.

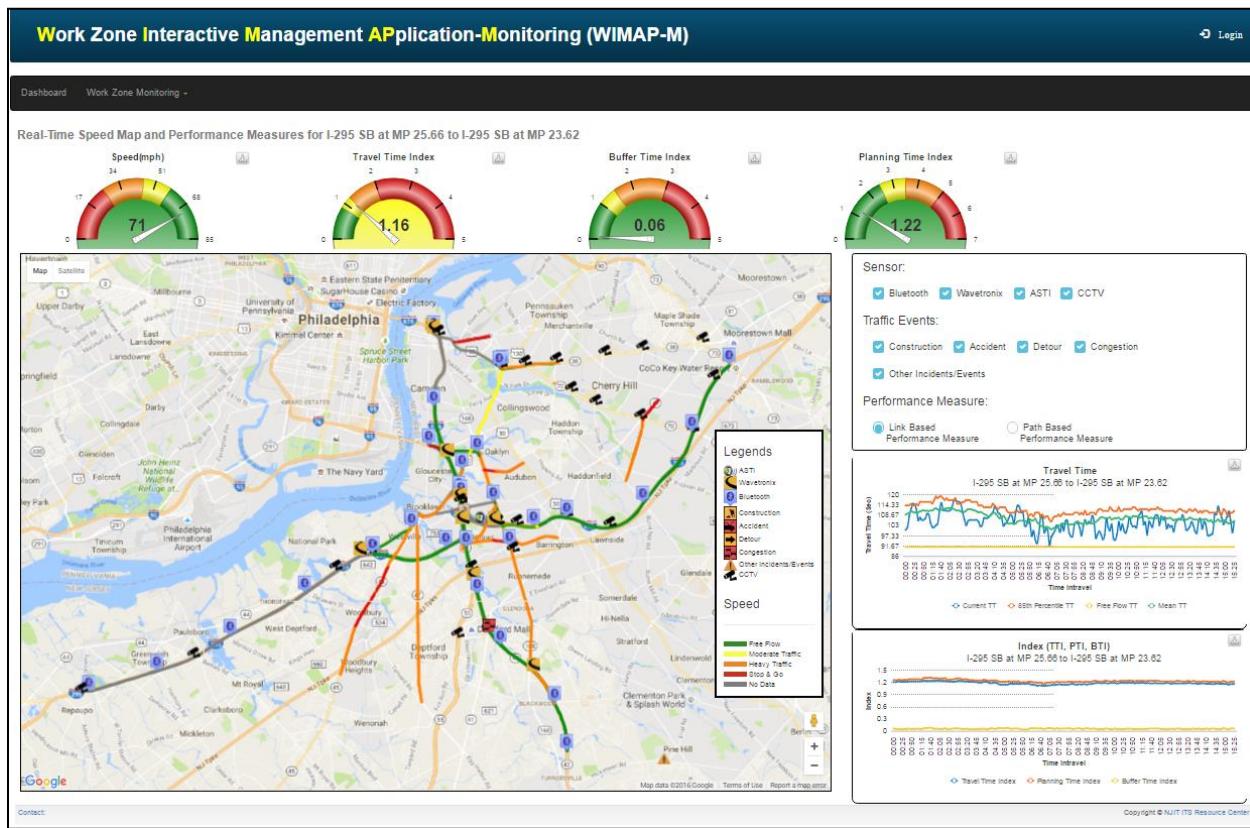


Figure 6. WIMAP Dashboard

In the dashboard, the real-time map (which is automatically updated every two minutes) shows the current traffic information in the vicinity of the work zone area. Four performance gauges in Figure 7 shown on the top of the map provide real-time speed, travel time index, buffer time index

and planning indexes of the selected roadway segment. In the right column, there is a panel which allows users to toggle ITS sensors, traffic events, and type of performance measure. Below are the two time-series plotting charts of the performance measures. The upper chart (see Figure 8(a)) displays current travel time, 95th percentile travel time, free-flow travel time, and the mean travel time for the time period selected by users. At the same time, the lower chart displayed in Figure 8 (b) shows variations of the reliability performance measures (i.e., TTI, PTI, and BTI) over time. It is worth noting that users can toggle any of these performance measures as desired for a more customized display.

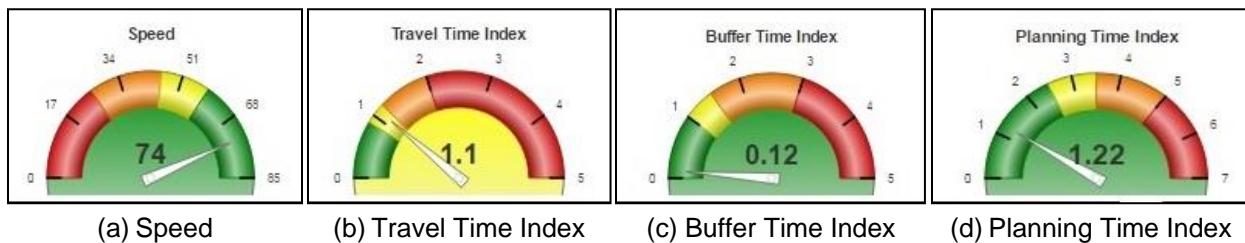
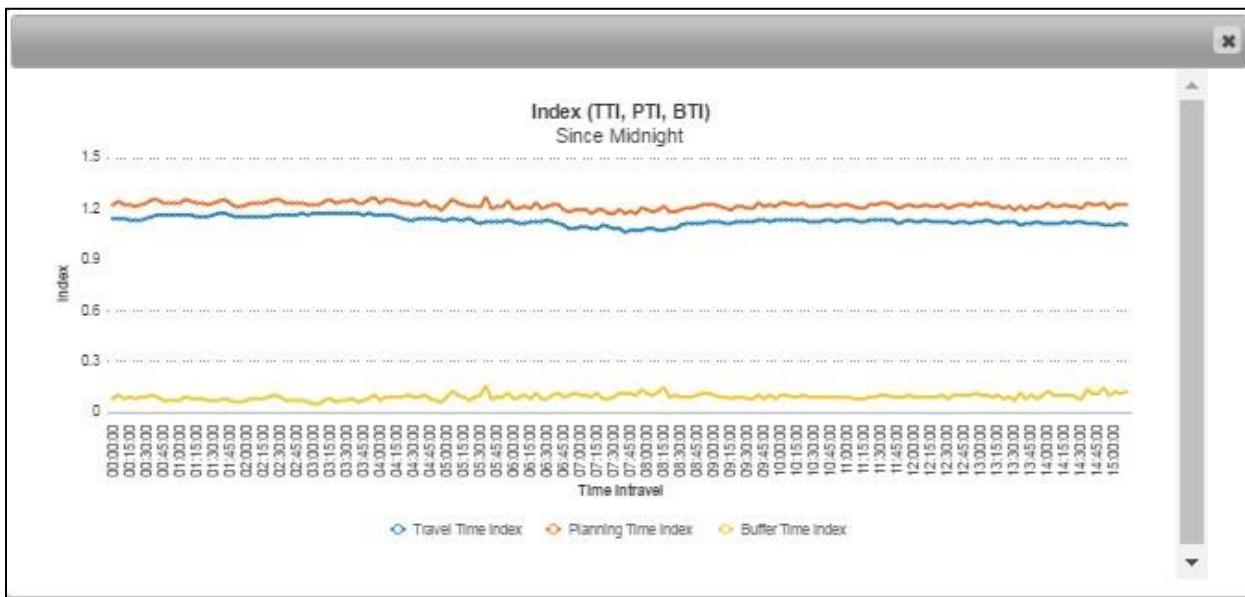


Figure 7. WIMAP Performance Measure Gauges

WIMAP receives RTMS (Wavetronix SmartSensor HD) devices data via the LTE commercial network and displays volume data at the nine locations (see Figure 3 (b)). When the RTMS devices were in planning stage, the roadway geometric conditions are considered in order to capture the traffic volumes that enter and exit the work zone area. Hence, WIMAP can also be used to demonstrate the volume composition of the traffic flow on a selected segment, as shown in Figure 9. The v/c ratio of a selected location is provided in the dashboard. It is important to clarify that the capacity of the roadway is established using a pre-determined prevailing value, which can be further fine-tuned in the future. In addition, the level of service is calculated based on the collected traffic data, such as free-flow speed, traffic volume, and vehicle classes.



(a) Travel Time Charts (Current, 95%, Free Flow, and Mean Travel Times)



(b) Index Charts (Travel Times, Planning Time, and Buffer Time Indices)

Figure 8. Performance Measure Charts

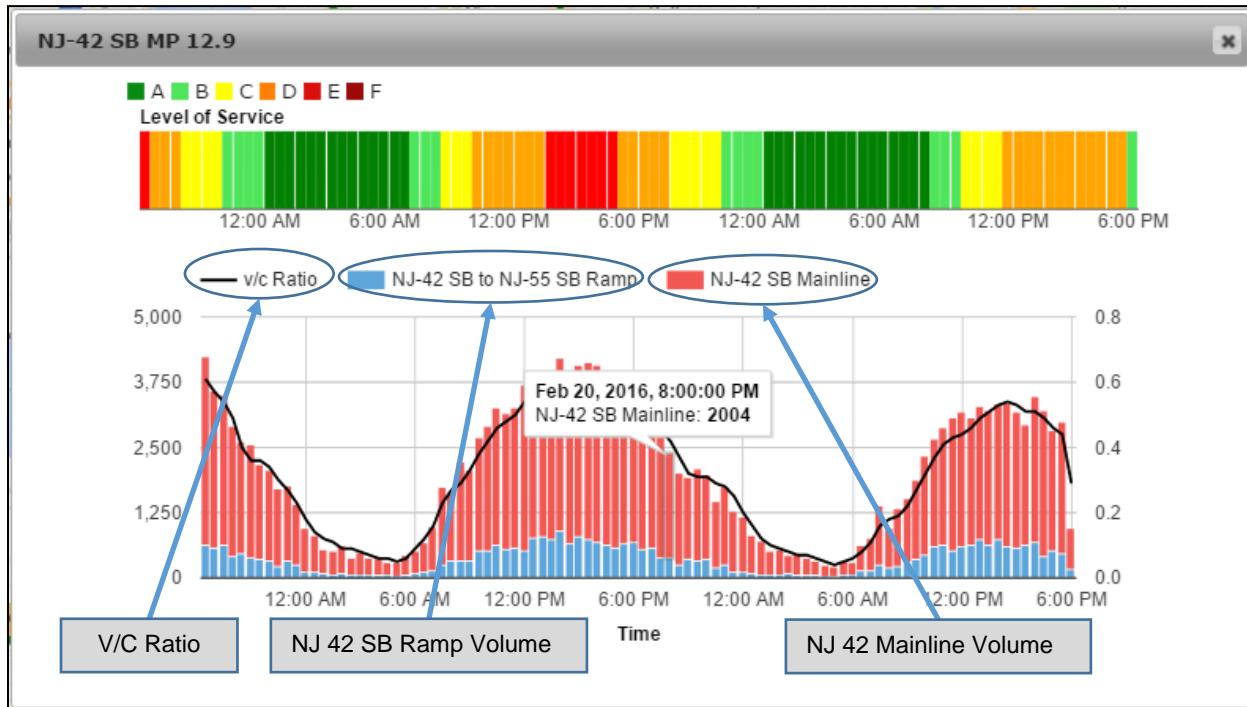


Figure 9. Volume-to-Capacity Ratio, Traffic Diversion, and Level of Service in WIMAP

## 2.7.2. Work Zone Monitoring

### 2.7.2.1. Archived Data Mapping

With WIMAP, users can interactively examine the current traffic congestion conditions by comparing the real-time traffic data with archived historical data. In the map-based comparison module, users are capable of analyzing the current traffic status with historical traffic information by selecting a specific day or multiple days for comparison. Figure 10 shows an example of selected maps, which allow the user to compare the live-traffic speed with the average speed for the last 5 weeks.

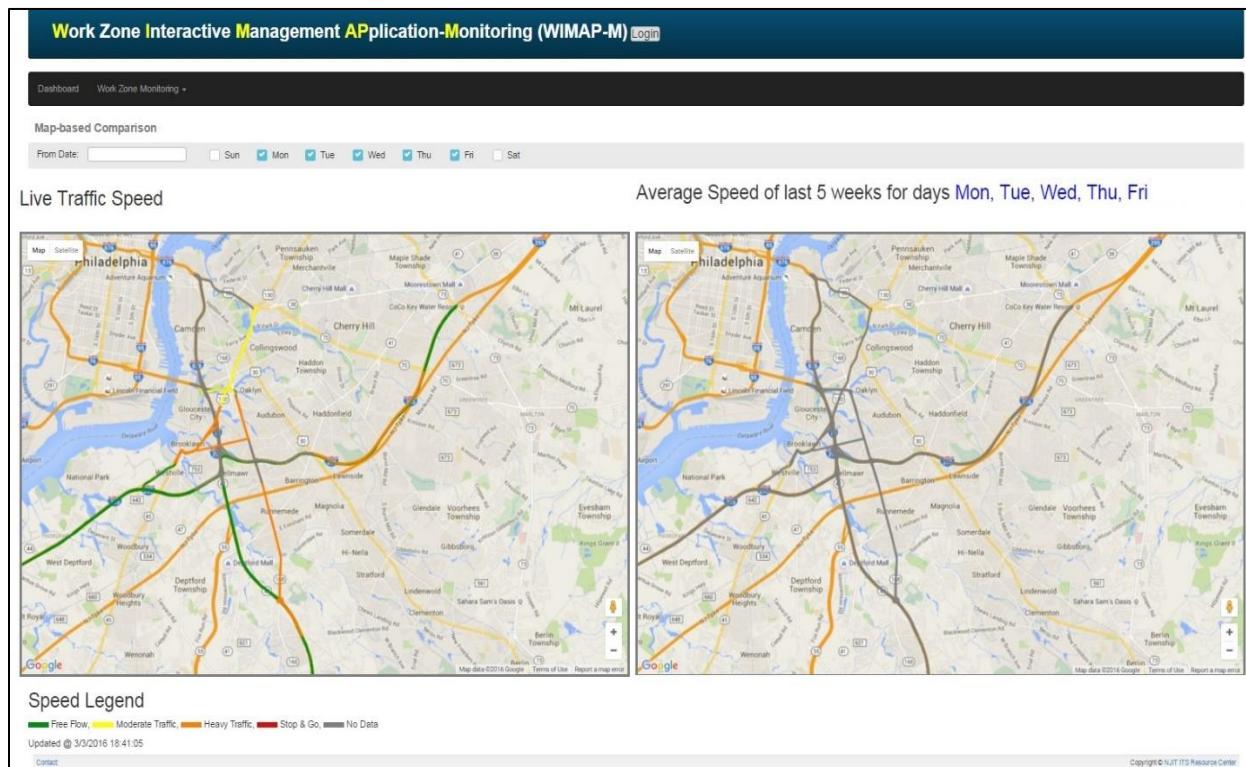


Figure 10. Congestion Comparison Map (Left: Real-time Traffic, Right: Historical Traffic)

### 2.7.2.2. Congestion Alert

Another useful module for WIMAP is the congestion detection algorithm. The definition of congestion is based on the bottleneck detection algorithm proposed by the VPP Suite [6] as demonstrated in Figure 11. WIMAP keeps scanning the real-time speed of a segment. Once the speed falls below 60% percentile of the free-flow speed, the segment is flagged temporarily, while WIMAP keeps monitoring the speed. If the speed drop lasts for more than 5 minutes, WIMAP tags the segment as congestion and makes the segment color red as displayed in Figure 11. The tagged segment is continuously monitored. When the speed regains over the 60% percentile of the free-flow speed for more than 10 minutes, WIMAP removes the tag and reverts the color to the original state.

Furthermore, there is a level-of-service overview available for WIMAP by utilizing the data derived from the RTMS. The map is an abstractive representation of the overall network and it allows an operator to easily obtain the general operational status of the network.

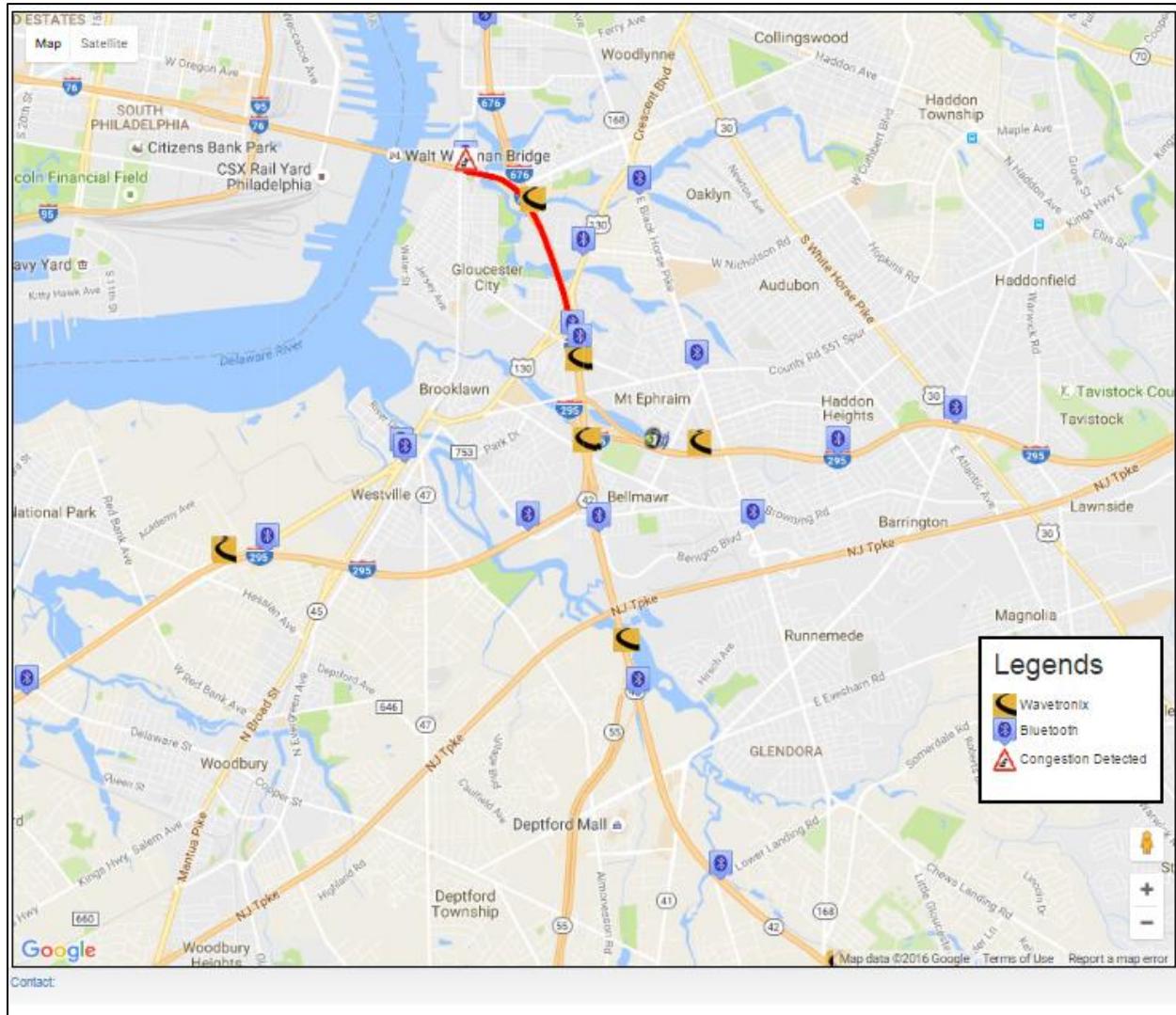


Figure 11. Congestion Detection Module

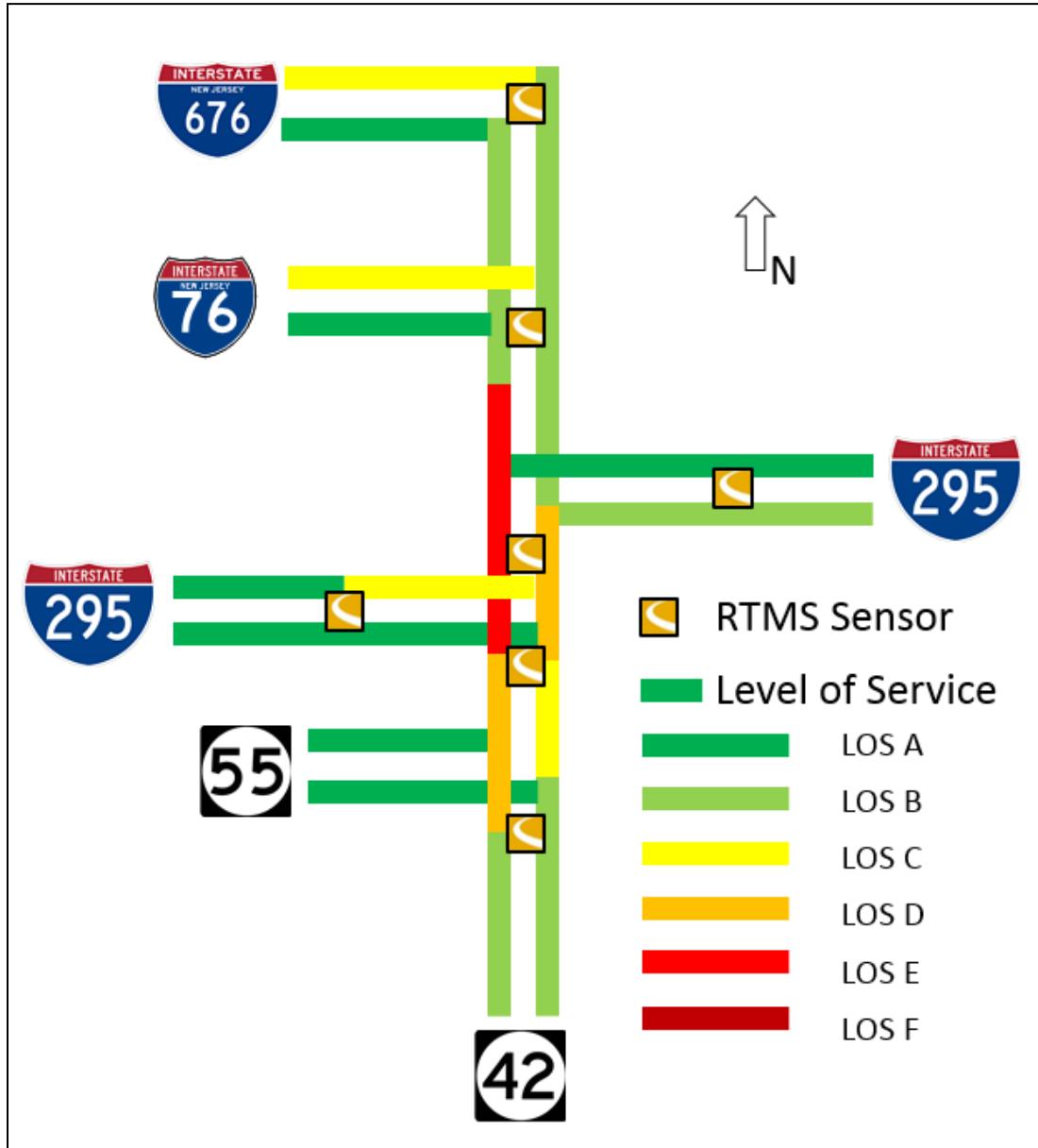


Figure 12. Real-time Network Level-of-service Overview

As shown in Figure 13, WIMAP has real-time CCTV feed available. The operator could further investigate the suspected congestion by visual confirmation, if there are available cameras in the surrounding area.



Figure 13. Real-time CCTV Video Feed

### 2.7.3. Report Generator

WIMAP generates two types of reports: a table structure report and a hybrid report with visualization. Both of the are presented in this section.

#### 2.7.3.1. Downloadable report

Besides real-time traffic information, historical data is also vitally important for stakeholders and transportation practitioners. WIMAP is programmed to automatically generate weekly and monthly performance summary reports for specified intervals. The report generator allows users to create performance measure charts that include historical incident information for a selected roadway segment. Moreover, the report generator allows for personalized use of the archived historical traffic data, giving the user the ability to specify route segment, starting date, ending date, time interval, time of the day (e.g. morning peak, afternoon peak, and non-peak periods). Figure 14 shows a snapshot of the WIMAP Report Generator. Performance measures directly obtained or derived from Bluetooth data are displayed in the report. Most common file formats, including Portable Document Format (PDF), Excel spreadsheet, Comma Separated Values (CSV) are available for export.

The screenshot shows the WIMAP-M application interface. At the top, there's a header bar with the title "Work Zone Interactive Management Application-Monitoring (WIMAP-M) Welcome Zjia" and a "Logout" button. Below the header is a navigation menu with links for "Dashboard", "Work Zone Monitoring", "Reports", "Devices", and "Site Administration". A sub-menu titled "Downloadable Reports" is open, showing a route segment selection dropdown set to "I-295 SB at MP 34.8 to I-295 SB at MP 32.4", and date/time selection fields for "Starting Date: 11/24/2016", "Ending Date: 11/25/2016", "Time Interval: 5 Min", and a dropdown for "PM-Peak(3PM to 8PM)". Below these is a "Show Report" button. The main content area is titled "Main Report" and displays a table of travel time data. The table has columns for "Collection Time", "Speed Travel Time", "Free Flow Travel", "85th Percent", "Mean Travel", "Travel Time", "Planning Time Index", and "Buffer Time Index". The data rows show measurements for various times on November 2, 2016.

Collection Time	Speed Travel Time	Free Flow Travel	85th Percent	Mean Travel	Travel Time	Planning Time Index	Buffer Time Index	
11/2/2016 3:00:00 PM	66	132	111	135	129.09	1.16	1.22	0.05
11/2/2016 3:05:00 PM	67	130	111	133	127.54	1.15	1.20	0.05
11/2/2016 3:10:00 PM	67	129	111	134	129.2	1.16	1.21	0.04
11/2/2016 3:15:00 PM	67	129	111	139	132.4	1.19	1.25	0.06
11/2/2016 3:20:00 PM	64	136	111	143	136.33	1.23	1.29	0.06

Figure 14. Downloadable Report

### 2.7.3.2. Route Segment Report

Besides the report pertaining to Bluetooth travel time, a more comprehensive report with all the applicable sources of data is available and shown in Figure 15. In the Route Segment Report, a formatted printable report is generated. Route segment mini map, performance gauge, and travel time indexes are included. Depending on the instrumentation of the RTMS data, the volume chart (e.g., Figure 8), if available, will be automatically added to the report.

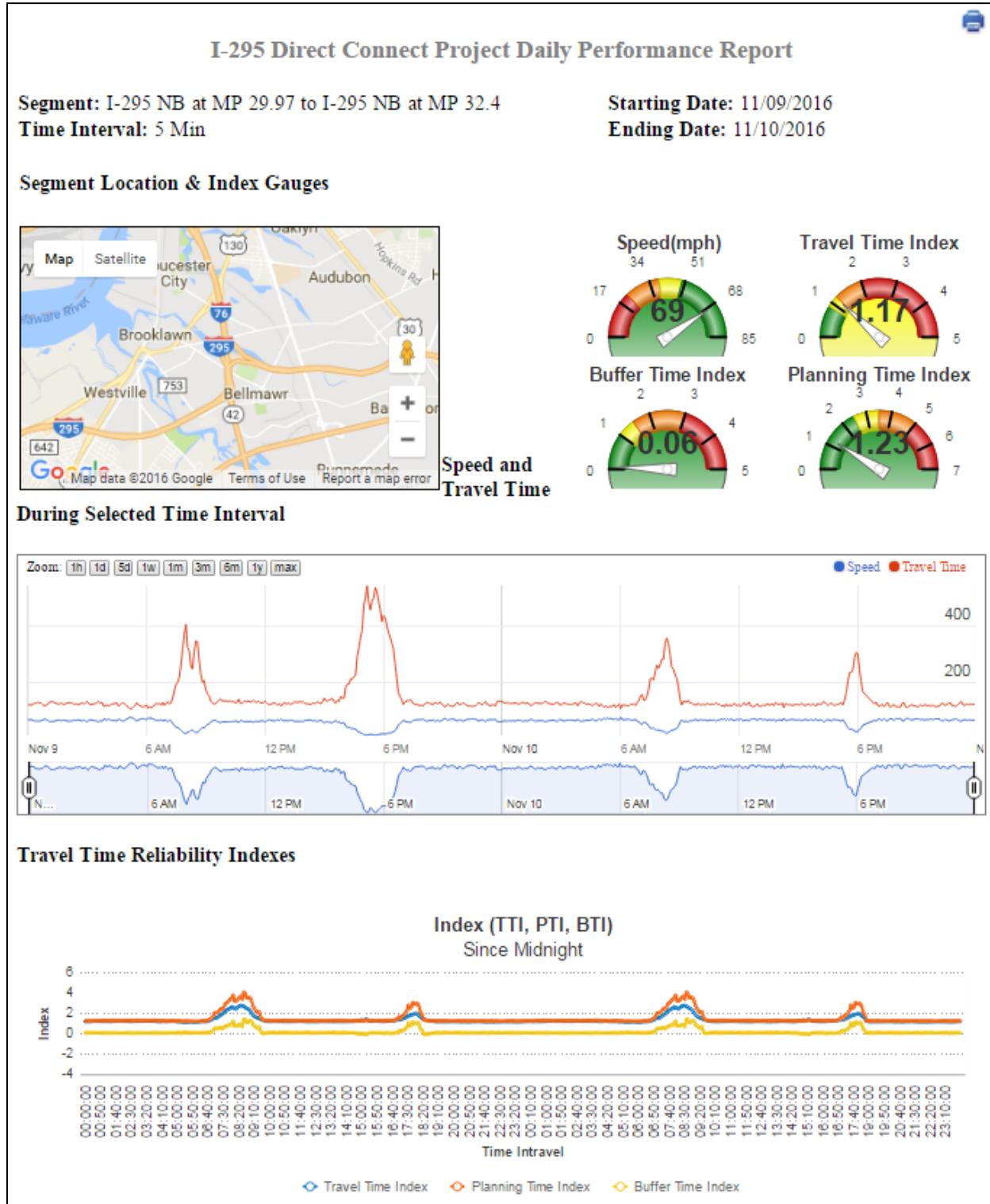


Figure 15. Downloadable Report (excerpt)

## 2.7.4. Device Location Mapping and Status

The Device module provides users with information regarding the status of all ITS devices device (e.g., Bluetooth sensors, RTMS devices) deployed in the proximity of the work zone, including device location and operational status, in a user-friendly map-based interface as shown in Figure 16(a). It provides valuable real-time information (Figure 16(b)) regarding the devices, for more efficient maintenance.

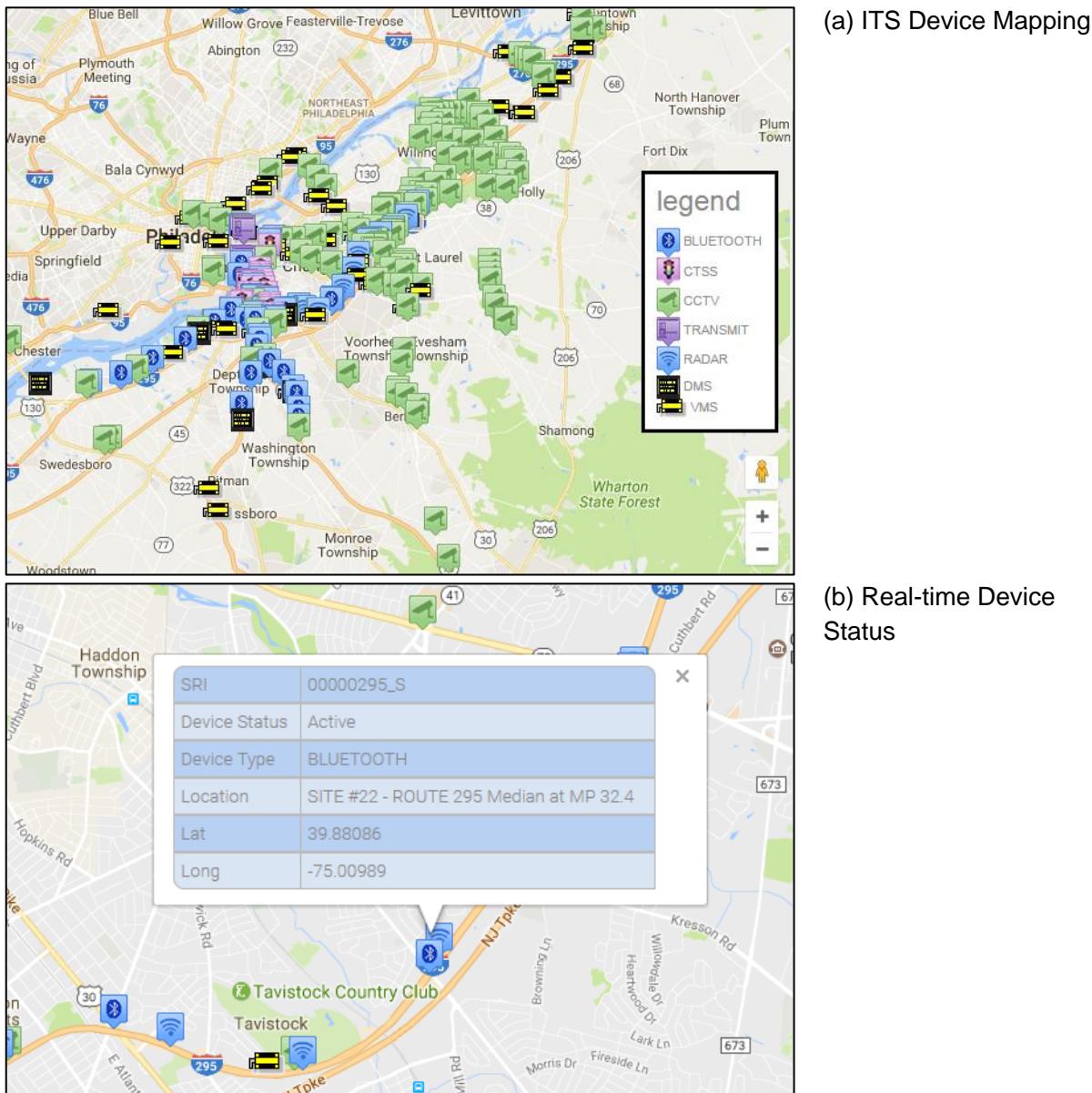


Figure 16. Device Module

### **3. Conclusions and Recommendations**

In response to ever-increasing traffic congestion caused by work zone activities, WIMAP was developed to collect, store, and analyze traffic data to help support real-time work zone monitoring and decision making in management scenarios. WIMAP is a web-based application primarily focusing on the operations occurring in a long-term work zone, the I-295 Direct Connection Project. By adopting performance measures recommended by MAP-21, WIMAP produces real-time mobility measures (e.g., percentile speed and travel time) and reliability measures (e.g., Travel Time Index, Buffer Time Index, Planning Index) in and around the I-295 Direct Connect work zone area.

The web service of WIMAP has been launched. It shows that the real-time mobility performance reports produced by WIMAP enable users to rapidly and precisely capture prevailing mobility conditions of work zone areas through MAP-21-based performance measures. The archived data map-based congestion comparison module also appeared to be informative for users to help in figuring out how the current traffic conditions are distinctive from historical congestion profiles. The report generator module producing user-customizable reports appeared to be one of the highlighted features of WIMAP. By allowing an interactive customization through the web-based interface of WIMAP, users are able to generate various types of performance reports, incorporating not only MAP-21 measures but also any historical events and activities that contribute to congestion of work zones.

WIMAP incorporates multiple data sources to precisely capture prevailing traffic conditions in real-time. The primary mobility data sources include Bluetooth sensors, RTMS devices (e.g., traffic counts), OpenReach (e.g., on-line roadway event data) and Plan4Safety (e.g., off-line crash records). WIMAP is expected to be the first on-line tool dedicated for use in a long-term work zone monitoring area. WIMAP deployment is anticipated to help support transportation management plans for long-term large-scale work zone projects.

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