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# Real-time performance measure monitoring system for long-term freeway work zone

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## Abstract

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. 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 paper 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.

## KEYWORDS:
Smart Work Zone, Probe Data, Web-Based Performance Monitoring System (WPMS)

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## Introduction

The Moving Ahead for Progress in the 21 Century Act (MAP-21) requires each metropolitan planning organization to establish surface transportation performance targets. The effective date for all measures was established in spring 2015 (1). Six sets of performance measures was established by MAP-21 such as national highway system (NHS) condition and performance, transit data of good repair, highway safety, transit safety, and congestion mitigation and air quality .

Work zone is a segment of a particular highway with activities of construction, maintenance or utilities work, whose impacts are usually referred to the deviation from the normal performance range of a given transportation network. It is estimated that work zones constitutes 10% of overall congestion, which is equivalent to over $700 million value of fuel loss (2). With an increase presence of work zones, it is vitally important to monitor the work zone impacts, so that a suitable plan may be developed to improve mobility and safety.

The New Jersey Department of Transportation NJDOT recently initiated the I-295 Direct Connection Project, a major highway interchange reconfiguration project for I-295/I-76/NJ-42 in Camden County. The project had commenced in March 2013 and it was expected to complete in 2021(3). Four sequential construction stages were assigned to different area of the overall construction zones. In the duration of the project, lane closure (both short-term and long-term) and traffic diversion was necessary and expected. With the anticipation of potential significant impact of the lane closure on the already saturated network, a real-time monitoring system was proposed in order to monitor traffic status, divert traffic flow, and gain readiness for emergency respond.

A web-based performance measure system, namely Work Zone Interactive Monitoring Application (WIMAP), was proposed, which has been developed by Intelligent Transportation System Resources Center (ITSRC) at the New Jersey Institute of Technology (NJIT) in research partnership with NJDOT. WIMAP is a web-based performance monitoring system (WPMS) specialized in work zone monitoring to capture instantaneous mobility measures proposed by MAP-21. It is tailored for NJDOT I-295 Direct Connect Project and expected to be expanded to monitor work zones throughout New Jersey. By collecting, archiving and analyzing the traffic data, the impact of the long-term work zone could be subsequently studied (e.g. recurring & non-recurring congestion, incident impact, and change of traffic pattern).

The remainder of this paper is organized as follows. The next section presents the literature review of available WPMSs and nationwide practices in the United States. Then, the details regarding WIMAP application and its key features will be discussed. Finally, the finding and recommendations will be concluded.

## Literature Review

In this section, relevant research activities are summarized by focusing on state-of-the practice of highway mobility monitoring systems and performance measures applied for work zone projects.

### *State-of-the practices of congestion monitoring system*

Not only do WPMSs help traffic operators, engineers, and planners to obtain real-time traffic flow information such as current and historical traffic condition, but it also facilitate road users to plan better for their journey (i.e., route choice and departure time); and therefore alleviate the overall congestion and achieve higher network efficiency.

iPeMS *(4)*and its variants are used by different public transportation agencies (e.g. DOTs, Harbor Department, and Regional Transportation Authorities, etc.) for the purposes of traffic operation and transportation planning. It was initially developed by University of California at Berkeley in conjunction with California Department of Transportation, which has been commercialized and tailored to customer's specifications (*8*) (e.g., availability of data sources and desired performance measure). Caltrans PeMS, a variant of iPeMS, was chosen to review Caltrans PeMS collects data from ITS sensors (e.g. loop detectors,

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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.

VPP Suite*(5)* , as a tool for congestion monitoring, is currently used by most state transportation agencies which are involved in the I-95 Corridor Coalition. VPP Suite utilizes the vehicle probe data provided by INRIX along with other data sources, such as accidents, volume counts and weather data. The suite allows users to monitoring real-time speed, travel time index (TTI), travel time reliability metrics, queue measurement, and bottlenecks.

PORTAL(*6*) was developed by Portland State University in conjunction with Oregon DOT. It was designated as the Portland region's official data archiving entity. It gathers speed, volume and occupancy data collected by inductive loop detectors which are part of the Portland region's advanced traffic management system (ATMS). In addition, it contains a comprehensive incident management system and transit data provided by TriMet and METAR weather data from NOAA.

PMMS (*7*) was developed by the Regional Transportation Commission (RTC) of Southern Nevada's. It supports TMC in monitoring and controlling traffic in the Las Vegas metropolitan area. It allows users to pull real-time and historical freeway performance information. Besides, incident data from Nevada Highway Patrol dispatcher is collected and archived in its database*(9)*.

## *Performance measures*

Speed is the intuitive performance measure when it comes to mobility and it is used by multiple WPMSs. Spot speed (i.e., time mean speed) collected by ITS device such as RTMS is an accurate representation of the speed of certain spot. However, spot speed is rarely meaningful in practices, especially when it comes to a long stretch of roadway. In that sense, space mean speed would be suitable for such long segment cases. While space mean speed is the most easily-obtained speed, it often produce a statistical bias particularly when applied to a long stretch of roadway*(13)*. That is, space mean speed may likely suffer from the risk of overly homogenizing the speed. In order to avoid biased estimation as possible as practically allowed, 15$^{th}$ percentile, 85$^{th}$ percentile, and 95$^{th}$ percentile are often used along with space mean speed to preserver the fidelity of the population. PMMS plots the 15$^{th}$ percentile and 85$^{th}$ percentile speeds which are applied to demonstrate the predominant speed range. PORTAL uses 15-min average speed as one of the mobility performance measure to display it in the real-time speed map. VPP Suite provides both mean speed and 95$^{th}$ percentile speed, while Caltrans PeMS only uses mean speed for the time being.

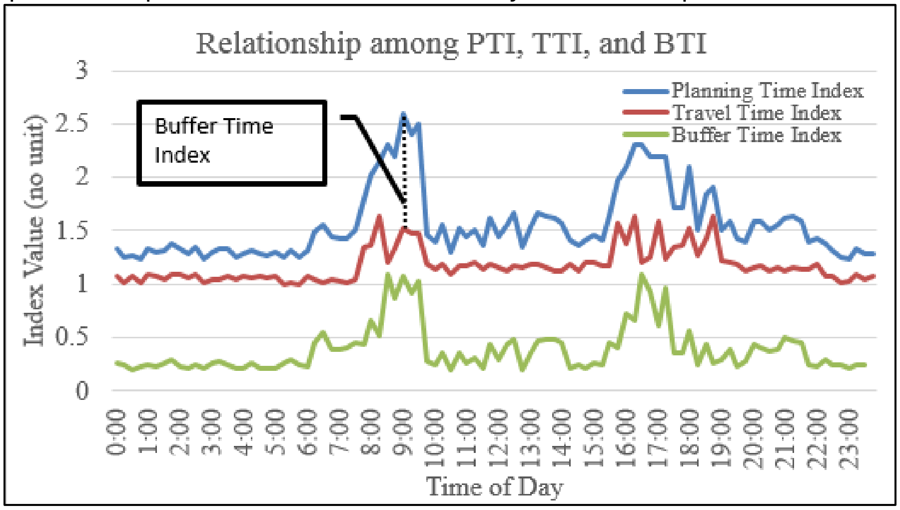


**Figure 1 Travel time reliability measures (synthesized data)**

Travel time is another straightforward mobility performance measure for travelers. More than likely, travelers are assumed making the route decision based on travel time. Average travel time could be

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somehow misleading in congested network, especially during peak hours of the day. Aiming to promote a performance measure which provides more accurate and practical information, MAP-21 proposes the use of travel time index, buffer index, and planning index to represent the network performance. They are the most effective methods to measure travel time reliability(*14*). The $95^{th}$ percentile travel time is applied to measure the delay for a specific roadway during the heaviest traffic days. It is also used as the worst day traveling indicator on particular roadway in a certain month. Buffer time index represents the extra time must be considered to ensure an on-time arrival at traveler's destination. Planning time index is the total time that a traveler should plan to ensure on-time arrival, expressed as a ratio of the planned total travel time and free-flow travel time of particular roadway. Figure 1 is a demonstration of the relationship between planning time Index and buffer time index. The mathematical definitions of these indexes are presented in Eq. (1) to Eq. (3), respectively. It has been shown that an increasing number of agencies throughout the country have begun using the travel time reliability indices, such as Federal Highway Administration, Minnesota DOT, and Washington State DOT. A study conducted by MN/DOT indicated that using travel time reliability indices, instead of average travel time, gained operational improvements*(14)*.

- $$\text{Travel Time Index} = \frac{\text{Average Travel Time}}{\text{Free-flow Travel Time}} \quad (1)$$
- $$\text{Planning Time Index} = \frac{\text{95th Precentile Traved Time}}{\text{Free-flow Travel Time}} \quad (2)$$
- $$\text{Buffer Time Index} = \text{Planning Time Index} - \text{Travel Time Index} \quad (3)$$

Congestion, as opposed to mobility, is also commonly used to measure or quantify the congestion in the network, WPESs use different indicators. Caltrans PeMS provides an algorithm to calculated delay based on user-defined reference speed. It also provides queue measure which is the ratio of VMT and VHT and it can be computed both in single location and over many different links. PMMS used a pre-defined four speed categories to classify congestions. PORTAL uses congestion frequency as an indicator of congestion. Besides traditional measures, the concept of productivity was introduced to the performance measure. However, such social-economics performance measures various among different geographical locations as well as demography.

When it comes to safety performance measure, iPeMS displays real-time accident information on the live traffic map by scraping data from TASAS(*15*) and CHP database. PMMS obtain incident data from the Traffic Incident Management Coalition, an agreement between the Nevada DOT and Nevada Highway Patrol. PORTAL and VPP suite do not have dedicated module for safety measure.

It is our anticipation that more and more WPMSs will emerge as the desire for real-time traffic monitoring and cost reduction of ITS devices increases. WPMSs will emulate among their peers in providing non-technical-user-friendly interface and enhanced visual presentations. There is, however, none of the available provides a dedicated platform for monitoring long-term work zone area as well as it potential impacts. WIMAP was, subsequently developed to fill such gas and it is expected to exemplify the real-time work zone monitoring practices nationwide.

## WIMAP System

The system architecture of WIMAP is shown in Figure 2. 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.

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## *Data sources*

One of the key features of WIMAP is the incorporation of multiple data. The real-time and historical traffic flow data are constantly being collected, archived and analyzed in the database server in NJIT. The primary data sources are: 1) Remote Traffic Microwave Sensor; 2) Bluetooth; 3) OpenReach event; and 4) Plan4Safety data sets. The WIMAP dashboard in Figure 3 maps the locations data collection devices including RTMS and Bluetooth in and around the work zone area.

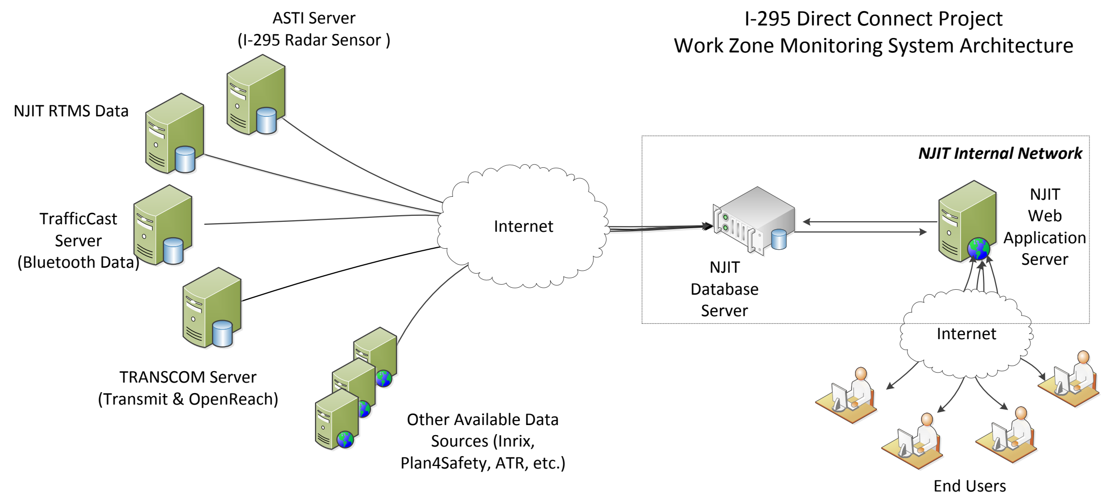


**Figure 2 WIMAP system architecture**

RTMS data provides the spot speed, traffic volume, occupancy for each lane of both directions. RTMS' are among the non-traffic-disruptive traffic flow monitoring technologies. They are typically deployed on the overhead area (light pole etc.) and the microwave is sent out intermittently to capture traffic flow information such as spot speed, lane occupancy, and traffic counts. In current, NJ-DOT deployed 12 RTMS devices to gather traffic counts, spot speed, and occupancy of the westbound of I-295.

Bluetooth has been recognized as 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 unique features of Bluetooth is to sense the identification of those devices by capturing their Medium Access Control (MAC) address without data authentication procedure. The travel time can be calculated, once a MAC address is detected by different Bluetooth readers in different locations. In this paper, Bluetooth data provided by a commercial vendor, TrafficCast, are being collected in and around I-295 work zone area. It is reported that the reported MAC address matching rate of is BlueTOAD approximately 4% of the daily traffic stream (*16*). Currently, a total of 41 Bluetooth readers are installed in and around the construction site of I-295 work zone area to capture route travel times and estimate route diversions by pairing each reader.

In addition, WIMAP also incorporates OpenReach and Plan4Safety data. OpenReach and Plan4Safety are both related to traffic incidents. The difference is: OpenReach is a real-time basis system which focuses on work zone related information and is updated every 2 minutes; while Plan4Safety is a historical dataset concerning crash records.

## *Dashboard*

The WIMAP main dashboard provides users with visual aids (e.g., charts, tables, graphs) for the performance measures as shown in Figure 3. This intuitive web-based interface serves as a portal that

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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, Microsoft ASP.Net, Google Maps, and Google Charts.

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 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 displays current travel time, 95th percentile travel time, free-flow travel time, and the mean travel time for the period selected by users. At the same time, the lower chart displayed in 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.

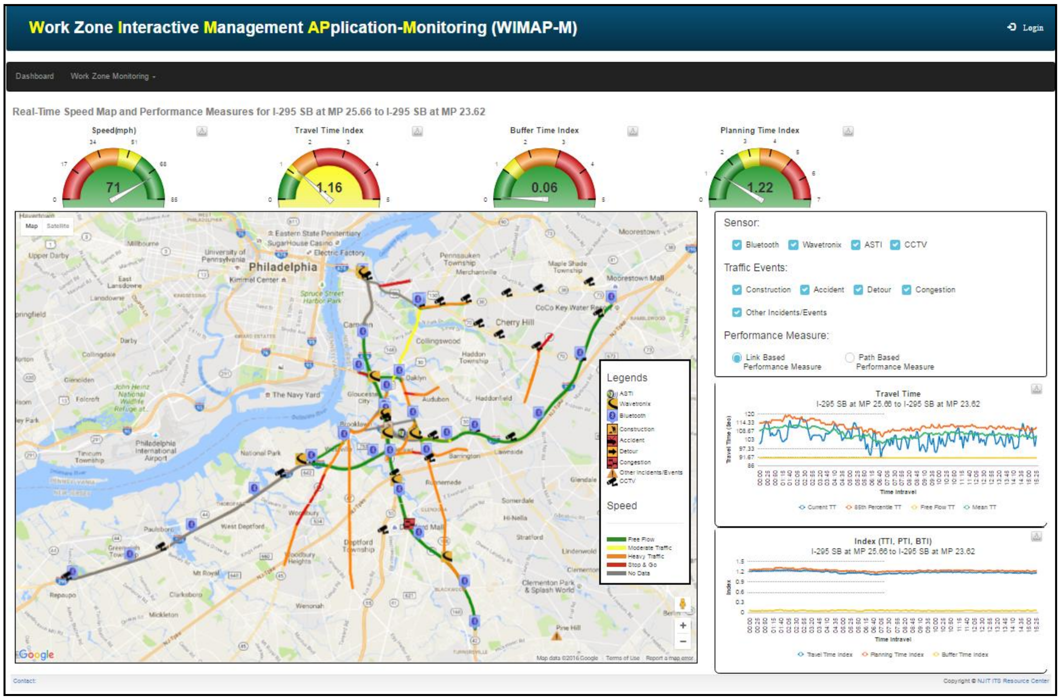


**Figure 3 WIMAP dashboard**

WIMAP receives data from RTMS devices via the 4G commercial network and displays volume data at the proposed locations. 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 4. 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.

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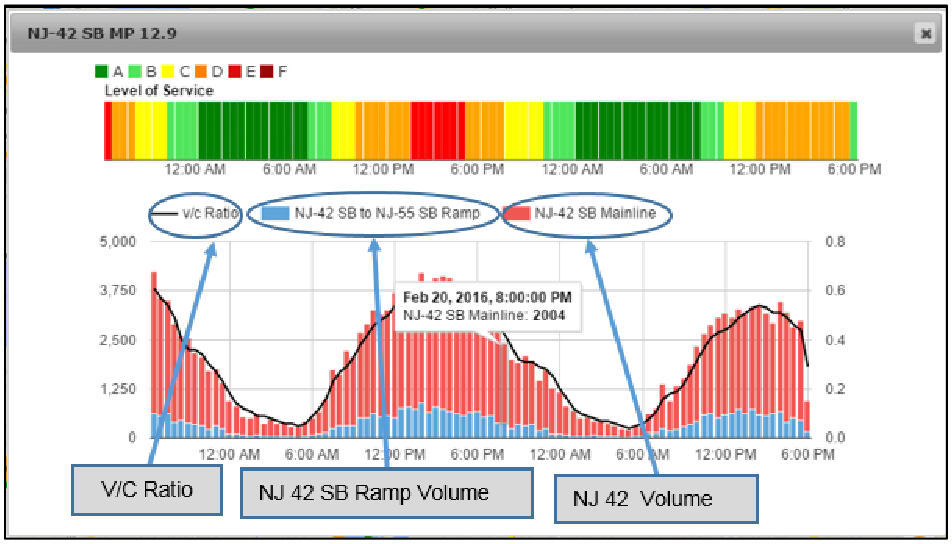


**Figure 4 Volume-to-capacity ratio, traffic diversion, and level of service in WIMAP**

*Congestion alert*

WIMAP provides automated congestion alerts by analyzing historical and prevailing traffic congestion data. The definition of congestion is based on the bottleneck detection algorithm proposed by the VPP Suite [6]. A simplified decision flow-chart for congestion detection is shown in Figure 5(left). 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 5(right). 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.

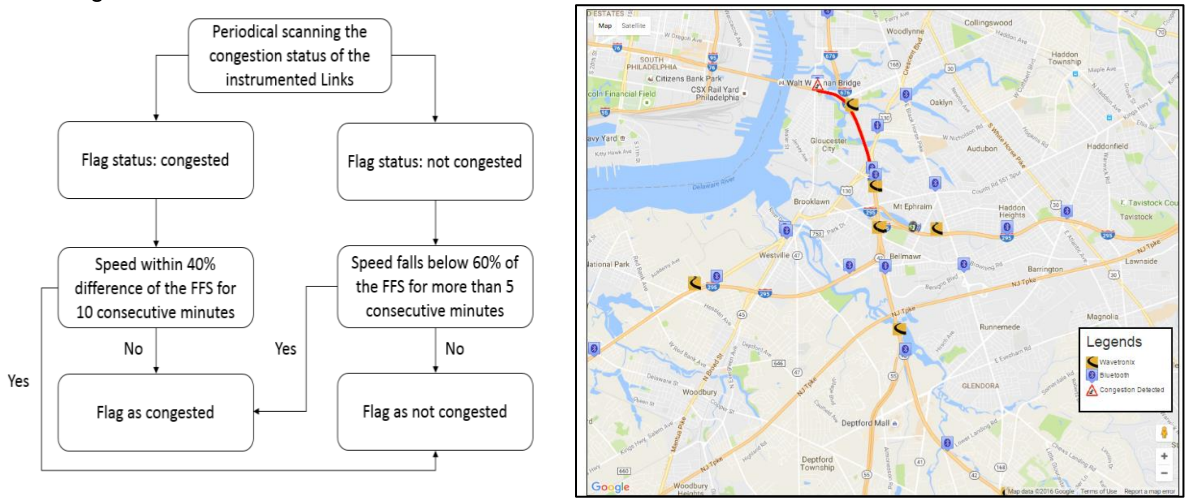


**Figure 5 Congestion detection (left: logic, right: congestion display)**

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### *Achieved data mapping*

With WIMAP, users can interactively examine the current traffic congestion conditions by comparing it with archived historical data.  In the map-based comparison module, the users are able to select the range of the historical date, day of the week for comparison in geo-spatial format. An average speed map for the last 5 weeks is generated alongside with the current live-traffic speed map as shown in Figure 6. Users are able to specify the certain data for the day of the week among historical data to tailor intended investigation.

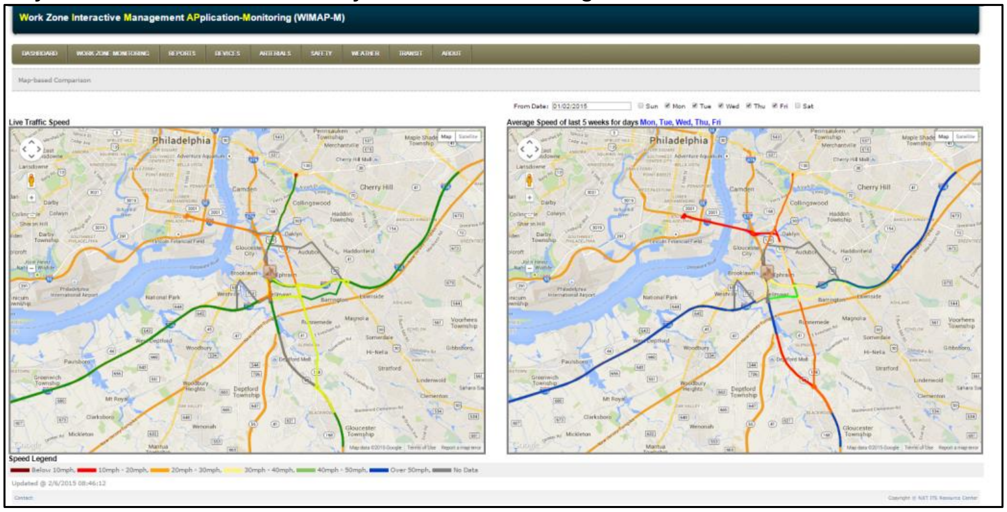


**Figure 6 Congestion comparison map (left: live traffic, right: historical traffic)**

### *Report generator*

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). 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.

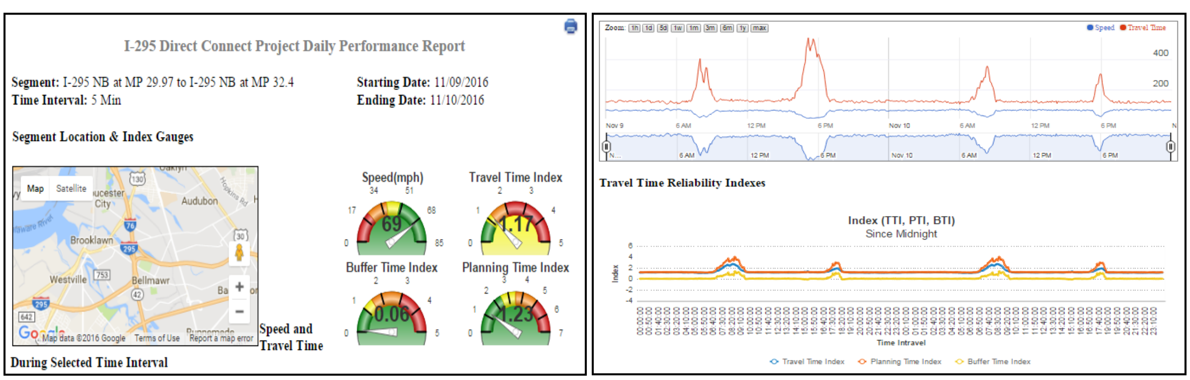


**Figure 7 Downloadable report (left: report part 1, right: report part 2)**

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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 7. 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, if available, will be automatically added to the report.

### *ITS device inventory*

The Device module provides users with information regarding the status of all ITS devices device (e.g., Bluetooth sensors and 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 8(left). It provides valuable real-time information in Figure 8(right) regarding the devices, for more efficient maintenance.

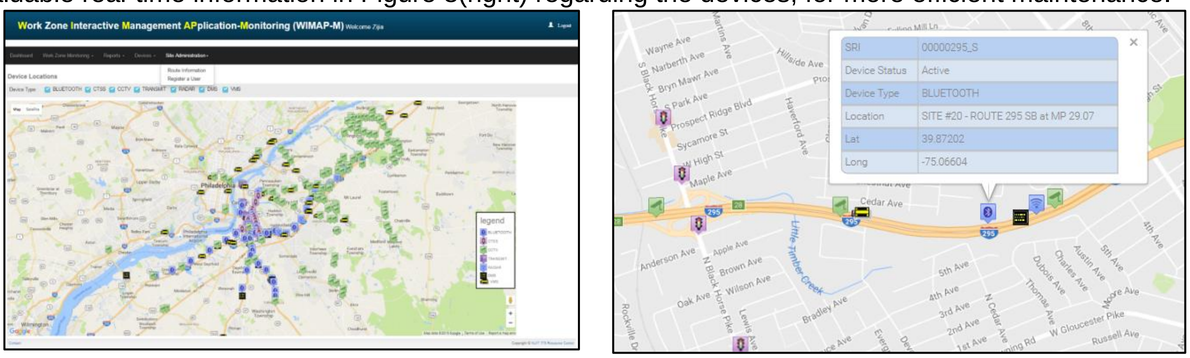


**Figure 8 Device inventory and real-time status (left: its device mapping, right: real-time device status)**

## Concluding Remarks

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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## Reference

1. *Performance Requirement Summary. Federal Highway Administration*, Washington, DC http://www.fhwa.dot.gov/tpm/about/schedule.cfm. Accessed 06/20/2014, 2014.
2. *Facts and Statistics - Work Zone Delay*. Federal Highway Administration. http://www.ops.fhwa.dot.gov/wz/resources/facts_stats/delay.htm. Accessed July 28, 2014.
3. *Traffic Technical Environmental Study of I-295/I-76/Route 42 Direction Connection*. New Jersey Department of Transportation, 2006.
4. *Caltrans Performance Measurement System*. California Department of Transportation. http://pems.dot.ca.gov/#33.9663,-117.8215,10. Accessed July 11, 2014.
5. *The Vehicle Probe Project Suite*. CATT Lab of University of Maryland. https://vpp.ritis.org/suite/#/dashboard/?lat=40.503301234667916;lon=-74.68975201929062;scale=8. Accessed July 11, 2014.
6. *Portland Oregon Regional Transportation Archive Listing Washington State Department of Transportation*. http://portal.its.pdx.edu/Portal/index.php/home. Accessed July 11, 2014.
7. *Performance Monitoring & Measurement System*. Regional Transportation Commission of Southern Nevada (RTC). http://bugatti.nvfast.org/Default.aspx. Accessed July 11, 2014.
8. C. Chen. *Freeway Performance Measurement System (PeMS)*. University of California, Berkeley, 2003.
9. G. Xie and B. Hoeft. *Freeway and Arterial System of Transportation Dashboard*. Transportation Research Record, Vol. 2271, 2012, pp. 45-56.
10. *Highway Performance Monitoring System*. Federal Highway Administration. https://www.fhwa.dot.gov/policyinformation/hpms.cfm. Accessed Nov. 15, 2014.
11. *Tri-County Metropolitan Transportation District of Oregon*. TRIMET. http://trimet.org/. Accessed Nov. 15, 2014.
12. *Meteorological Aerodrome Report.* Australian Bureau of Meteorology. http://www.bom.gov.au/aviation/observations/metar-speci/. Accessed Nov 15, 2014.
13. E. T. Donnell and S. C. Hines. *Speed Concepts: Informational Guide*. 2009.
14. *Travel Time Reliability*. Federal Highway Administration, Washington, DC.
15. *Traffic Accident Surveillance and Analysis System (TASAS)*. California Department of Transportation. http://www.dot.ca.gov/hq/esc/oe/project_ads_addenda/04/04-1637U4/Reference%20Documents/Operations%20and%20Maintenance/Caltrans%20TASAS%20Accident%20Data.pdf. Accessed Nov. 15, 2014.
16. *Travel Time Data Collection White Paper*. Florida Department of Transportation.
17. TRANSCOM. https://data.xcmdata.org/DEWeb/Pages/index.jsp. Accessed July 29, 2014.