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**Next Generation Performance Monitoring
Data Needs for Nevada DOT**



December 2014

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Next Generation Performance Monitoring Data Needs for Nevada DOT

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16. Abstract This report examines state-of-practice for performance measurement and focuses on federal requirements for traveler information mandated by SAFETEA-LU Section 1201 Real-Time System Management Information Program. Guidance for November 2016 compliance is provided by identifying 17 candidate Routes of Significance within the Las Vegas metropolitan area based on usage criteria. A prioritized list of required sensor locations for full route coverage of these routes is provided. It is recommended that NDOT explore the use of private probe data to generate travel time information along arterial routes.			
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Executive Summary

This report examines recent changes in state-of-practice to compute performance measurements and new legislation focused on performance-based outcomes. MAP-21 legislation identified congestion reduction as a major goal area for the country and helped establish a Real-Time System Management Information Program (RTSMIP) that requires states to provide traveler information related to construction, weather, incidents, and travel-time along all interstates and in large metropolitan areas which includes the Las Vegas area in Nevada.

This report finds that the main barrier to meet the SAFETEA-LU Section 1201 RTSMIP requirements for metropolitan area routes of significance by the November 8, 2016 deadline is the need for travel time information. Routes of significance need to be established before selecting technologies to address travel time. A preliminary list of routes were identified by screening the Las Vegas Valley road network based on VMT, daily flow, average speed, road type designation, and geo-spatially which include

Route	Dir.	Route	Dir.
1 (SR 573) Craig Rd	E-W	9 (SR 582) Boulder Hwy.	N-S
2 (SR 159) Charleston Blvd.	E-W	10 (SR 595) Rainbow Blvd.	N-S
3 (SR 589) Sahara Ave.	E-W	11 (SR 607) Eastern Ave.	N-S
4 (SR 593) Tropicana Ave.	E-W	12 (SR 612) Nellis Blvd.	N-S
5 (SR 592) Flamingo Rd.	E-W	13 Martin Luther King Blvd.	N-S
6 (SR 160) Blue Diamond Rd.	E-W	14 Las Vegas Blvd (Strip)	N-S
7 (SR 146) St. Rose Pky.	E-W	15 US 95	N-S
8 Summerlin Pky.	E-W	16 US 93	N-S
		17 CC 215	

In order to fully cover these routes, 26 new Radar installations are recommended at the following coordinates:

	Latitude	Longitude		Latitude	Longitude
CC 215					
1	-115.288851	36.077549	2	115.288851	36.092776
3	-115.295786	36.106194	4	-115.313425	36.118858
5	-115.335286	36.131069	6	-115.341611	36.198517
7	-115.334853	36.212604	8	-115.325526	36.228213
9	-115.325145	36.238587	10	-115.316769	36.24525
11	-115.314961	36.255053	12	-115.322956	36.259431
13	-115.32762	36.268663	14	-115.327144	36.276753
15	-115.318078	36.282547	16	-115.304515	36.280049
17	-115.277389	36.278621	18	-115.237058	36.276122
19	-115.205649	36.276122	20	-115.178523	36.291827
21	-115.150683	36.293968	22	-115.11856	36.290399
23	-115.081441	36.291113			
Summerlin Pky.					
1	-115.322718	36.194745	2	-115.307728	36.186893
3	-115.294165	36.179754			

and 18 camera installations are recommended at

	N-S Street	E-W Street		N-S Street	E-W Street
1	S Rainbow Blvd	Edna Ave	2	S Rainbow Blvd	W Tropicana
3	S Rainbow Blvd	W Hacienda	4	S Rainbow Blvd	Patrick
5	S Rainbow Blvd	Alta Dr	6	S Valley View Blvd	W Charleston
7	Apple Dr	W Charleston	8	S Lamb Blvd	E Charleston
9	Nellis Blvd	E Charleston	10	S Maryland Pky	E Charleston
11	S Eastern	E Desert Inn	12	Lindel Rd	W Sahara
13	S Town Center	W Sahara	14	S Lamb blvd	E Sahara
15	Nellis Blvd	E Sahara	16	S Las Vegas	Cactus Ave
17	N Martin L King	Gowan	18	N Martin L King	Carey Ave

It is recommended that NDOT initiate conversations with third party private probe data providers to fill arterial data gaps without the high cost of hardware installation and maintenance since these have been proven to meet the reporting accuracy and availability requirements. This type of data would take advantage of newer social media techniques for prompt response times and provides a scalable solution that could be applied throughout Nevada, not just Las Vegas.

The outputs from this research include:

- Reports on data collection technology, performance measures, and recommendations to meet upcoming real-time data requirements for metropolitan areas.
- Las Vegas ITS inventory with associated coverage maps and data gap identification in GIS format.
- The Performance Measurement Research System with web interface to 1-minute resolution transportation data.
- An early congestion prediction algorithm using historical traffic measurements for highways which also resulted in a submission to TRB.

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Chapter 1

Introduction

1.1 Objectives

This study explores the collection of performance measures as designated by the Real-Time System Management Information Program (RTSMIP) included in Section 1201 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). This work primarily focuses on the steps required to satisfy the November 8, 2016 requirement for on Routes of Significance (ROS) within metropolitan areas within the Nevada. The study examines the Las Vegas Valley metro area to:

- determine a criteria to define meaningful routes of significance and identify Las Vegas ROS.
- determine the critical data gaps within the ROS and make suggestion to fill these gaps.

1.2 Organization

In Chapter 2, a review of data collection techniques and performance measures is presented. The current state-of-practice and national best-practices for urban/rural data collection technologies, strategies and derived performance measures is reviewed.

Chapter 3 reviews legislative requirements outlined in SAFETEA-LU Section 1201 for the establishment of a Real-Time System Management Information Program (RTSMIP) to provide consistent traveler information on major state roadways. The chapter highlights state examples to define important routes of significance (ROS) in large metropolitan areas and introduces private probe data services to obtain system-wide travel time measures.

An assessment of Nevada's RTSMIP program and ROS recommendations for Las Vegas are presented in Chapter 4. A data gap analysis was performed using geographic information system (GIS) tools to identify and prioritize the installation locations of new sensors to meet the 2016 metropolitan reporting requirements.

Chapter 5 describes a new Performance Monitoring Research (PMR) system that provides access to traffic measurements at one minute resolution suitable for calculating more advanced performance measures and real-time data.

In Chapter 6, a field study on congestion performance measurement is performed using the PMR. The demonstration application is able to use pattern recognition techniques to predict congestions a few minutes before it begins.

Finally, in Chapter 7 concluding discussion and recommendations for data collection gaps in arterial travel time are presented for final guidance through the RTSMIP November 8, 2016 final deadline. This section also highlights the outputs of the research project.

Chapter 2

Data Collection and Performance Measurement Background

Over the past few years, there has been increased emphasis on system-wide performance measurement. In July 2012, President Obama signed Moving Ahead for Progress in the 21st Century (MAP-21) into law to fund long-term highway investments [1]. A critical component of MAP-21 legislation is the establishment of a performance- and outcome-based surface transportation program. This performance management aims to increase efficiency and maximize return on investments.

National performance goals were identified for the seven areas in Table 2.1.

Table 2.1: MAP-21 National Performance Goals

Goal Area	National Goal
Safety	To achieve a significant reduction in traffic fatalities and serious injuries on all public roads.
Infrastructure condition	To maintain the highway infrastructure asset system in a state of good repair.
Congestion reduction	To achieve a significant reduction in congestion on the National Highway System.
System reliability	To improve the efficiency of the surface transportation system.
Freight movement and economic vitality	To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development.
Environmental sustainability	To enhance the performance of the transportation system while protecting and enhancing the natural environment.
Reduced project delivery delays	To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion through eliminating delays in the project development and delivery process, including reducing regulatory burdens and improving agencies work practices.

These goal areas directly affect state DOT divisions. Safety goals can help develop incident management strategies to reduce crashes. Planning divisions will have the necessary data to

prioritize projects based on a particular criteria such as delay from congestion. The effects of construction and intelligent transportation system (ITS) improvement on travel time, speed, and delay can be directly characterized by Operations.

In order to meet these goals, performance measures must be established with regard to

- Pavement condition on Interstate System and National Highway System (NHS)
- Performance of Interstate and NHS
- Bridge condition on NHS
- Fatalities and serious injuries on all public roads
- Traffic congestion
- On-road mobile source emissions
- Freight movement on Interstate

In each category, states were required to set performance targets based on these measures which required the definition of measures of effectiveness (MOE) [2]. The MOEs can be determined by having reliable and robust data sources and derived measures to address performance goals.

In the following Sections of this chapter, data collection techniques and common derived performance measures are highlighted.

2.1 Data Collection Techniques

Sensors and detection technologies have been in use by transportation engineers for many years. Fundamentally, the presence of a vehicle is desired. However, newer sensing technology is providing significantly more than just the count of passing vehicles including the speed, type of vehicle, and travel time. In the last few years, new crowd sourced data collection has been enabled by widespread deployment of GPS receivers and cellular networks. Beyond position information, social platforms are providing detailed information by the traveling public to improve performance.

The following section provides a short summary of leading sensing technologies:

- Intrusive Detector Technologies
 - Inductive Loop
 - Magnetic Detector
 - Pneumatic Road Tube
 - Weigh-in-Motion
- Non-Intrusive Detector Technologies
 - Active and Passive Infrared
 - Microwave Radar
 - Ultrasonic and Passive Acoustic
 - Cameras and Video Image Processing
 - Combined Detector Technologies
- Off-Road Technologies

- Communication Systems
- Probe Vehicle
- Pedestrian and Bicycle Detection

More detailed treatment of these technologies can be found in [3–5].

2.1.1 Intrusive Detector Technologies

Intrusive detector technologies typically work very well at detecting vehicles because of “contact” with a sensor strategically placed on the roadway. They are mature technologies that are favored by transportation engineers. However, these detectors have to be placed on or in the roadway which requires lane closures and regular maintenance which can be costly.

Inductive loops are popular detectors composed of looped wires that measure a change of inductance when a vehicle passes over it in order to measure presence, volume, occupancy, speed, and basic length classification. However, loop installation is a disruptive process to cut the pavement and seal the loop inside. They have a high failure rate due to poor installation or environmental conditions such as the extreme heat in Las Vegas.

Similar in operation to loops, magnetic detectors can detect the presence of a vehicle based on its metal composition affecting the Earth’s magnetic field. These can be small and effectively monitor slowly moving and stationary vehicles.

The simple low cost pneumatic tube was developed in the 1920s. When a vehicle drives over a tube placed over the roadway, air pressure in the rubber tube changes. The tubes are usually used for short-term traffic counting since they must be placed over the road and can measure volume, speed, and some classification by axle count and spacing.

Strain gauges are used in weigh-in-motion systems to measure weight for each axle of a vehicle. Based on calibration parameters for speed and pavement suspension dynamics, the weight of a vehicle can be measured and used for truck load restrictions.

2.1.2 Non-Intrusive Technology

In contrast to Intrusive Technology, Non-Intrusive technology can be installed and maintained without the need to disrupt traffic. Often times these sensors are installed on the side of the roadway and multiple lanes can be monitored with a single sensor. Since there is no longer a direct contact point, these sensors need extra processing to discern a vehicle from a sensor signature.

Active Infrared systems utilize low energy invisible infrared light from diodes or high energy laser diodes to measure the time for reflected energy to return to the detector. When a vehicle is present, the time is lower. These systems can be designed with multiple beams to measure speed and are used in a variety of applications such as toll collection, bridge/tunnel clearance verification, and as a trigger for enforcement cameras.

Using Radar system, volume, occupancy, speed, and classification can be measured. Doppler Radars measure the shift in frequency from a moving vehicle so requires a minimum speed for detection. Frequency modulated continuous wave detectors have increased reliability because it measures distance along with speed to handle multiple moving sources in its view.

Active ultrasonic sensors operate in a manner similar to Doppler Radar systems but use ultrasonic sound waves rather than microwave. Passive acoustic sensors are microphones that measure the noise of a passing vehicle. Sound-based systems have limited range due to the prevalence of disruptive noise source.

Cameras have become a favorite transportation management technology because they are naturally accessible for human operators. Operators can view cameras and understand the traffic situation. Automated analysis systems have been designed using video image processing techniques to detect vehicles in images based on motion causing changes in pixel intensities. The computer vision community has been very active in developing advanced algorithms which are able to detect, track, classify, and measure vehicles. In addition, cameras provide area coverage for density, can be used for travel time, as well as intersection analysis of queue length and turning movements. However, these have been slow for adoption because of limited applicability during adverse weather or when lighting is poor (i.e. sunrise or sunset).

Newer sensing technologies are combining sensor types to overcome a single technology's weakness. For example, camera and radar combinations are now on the market that can help solve visual ambiguity with depth information. These provide Radar measurements but also visual tracking of an area and potential for applications like license plate recognition.

2.1.3 Off-Road Technologies

Off-road sensing technologies utilize communication channels for detection. Specialized transportation hardware can be mounted on the side of the road for direct communication such as RFID used with electronic toll-collection systems. The DSRC band has been allocated specifically for automotive use and ITS. However, the recent trend has been to move away from specialized equipment and more toward consumer mobile technology with the rapid growth of smart devices.

Probe vehicle technology can fulfill real-time monitoring applications. A probe vehicle is a special vehicle that is sent into the road network to take specific measurements. This is very useful for direct measurement of travel time, however is costly for a DOT to run at large scale. Bluetooth sensors are being deployed to utilize private vehicles as probes. Bluetooth stations communicate with phones and use unique identifiers to calculate the time to travel between important roadway points. One drawback of this technology is that Bluetooth is a short range communication protocol and must be mounted close to the road and it requires an active Bluetooth connection on a cell phone. Currently, penetration rates may not be high enough to obtain significant measurements.

GPS enabled smart devices are able to actively track position and speed and transmit this information to private companies that provide transportation services. These private probe vehicle companies partner with professional drivers (e.g. taxi and fleet vehicles), use in-vehicle navigation devices, and utilize smart phone apps to collect data over large areas and provide access to cleaned and processed data to interested parties. Using GPS it is possible to directly measure travel time using an individual vehicle but typically aggregation methods are utilized.

2.1.4 Pedestrian and Bicycle Detection

Similar sensing technologies for vehicles (infrared, microwave radar, ultrasonic, magnetic, and piezoelectric) have been used for pedestrian and bicycle detection. The sensors need to be modified to handle smaller objects with lower speeds. These sensors are mounted curbside and can supplement pushbutton pedestrian indicators. However, very few systems are commercially viable with use in only a few jurisdictions. In fact, pedestrian and bicycle utilization is typically not well understood.

2.2 Performance Measures

System-wide performance monitoring and measurement methods and tool are critical research areas for state DOTs. Each must develop a set of performance targets and goals based on performance metrics from which to gauge the ability to meet objectives. The key performance areas are:

- Mobility
- Accessibility
- Reliability
- Safety
- Environment
- Cost
- Infrastructure Condition
- Economic Impact
- Industry Productivity
- Traffic Data Quality
- Congestion (through mobility and reliability)

Table 2.2 lists a number of measures that are commonly used to assess the different areas. (See Appendix A for a full list of measures in use around the country). Often times, the use of a performance measure and its calculation is mandated by law. As an example, many of the safety performance measures are required by Federal rule for reporting the the National Fatality Analysis Reporting System (FARS). Operational measures such as travel time, speed, and delay are most effective for public reporting since they relate directly to what is experienced by the traveler while derived measures are more relevant to policy planners [2]. In a similar vein, the commonly used level of service (LOS) grade is a simple measure that can provide a quick snapshot for roadway performance that can be included in high-level executive reports but does not provide sufficient granularity for engineering. Mobility and Reliability measures help define Congestion statistics which are useful for traveler information.

In Nevada, the Integrated Transportation Reliability Program (ITRP) has been working to provide NDOT with a system of performance measures that provide meaningful ways to improve operations, better inform planning and programming, and to effectively track progress toward a more reliable transportation system. The Connecting Nevada projects has focused on communication and state-wide coordination for more comprehensive planning.

Table 2.2: Common Performance Measures

Measure	Description
Mobility	
Volume-to-Capacity Ratio (V/C Ratio)	The volume divided by capacity. The volume is often estimated as the 30th yearly highest volume available.
Level of Service (LOS)	A grade interval expressing how well a roadway segment is serving its traffic. It is graded from A to F, which A means free flow and F means very congested. LOS is based on a (V/C Ratio) and has long been used as the primary measure of congestion for planning purposes.
Annual Hours of Truck Delay (AHTD)	Travel time above the congestion threshold in units of vehicle-hours for trucks on the Interstate Highway System
Reliability	
Reliability Index (RI80)	The ratio of the 80th percentile travel time to the agency-determined threshold travel time.
Safety	
Number of Traffic Fatalities	Moving average of the number of traffic fatalities within 3 or 5 year intervals.
Environment	
Criteria Pollutant Emissions	Daily kilograms of on-road, mobile source criteria air pollutants (VOC, NO _x , PM, CO).
Cost	
Fuel Consumption per Ton-Mile	The cost associated with transport that is related to highway condition.
Infrastructure Condition	
Pavement Condition	Percentage of 0.1 mile segments of non- Interstate NHS pavement mileage in good, fair and poor condition based on the following criteria: good if IRI < 95, fair if IRI is between 95 and 170, and poor if IRI is greater than 170.
Bridge Condition	Percentage of National Highway System bridges in good, fair and poor condition, weighted by deck area.
Traffic Data Quality	
Accuracy	The measure or degree of agreement between a data value or set of values and a source assumed to be correct.
Completeness (Availability)	The degree to which data values are present in the attributes.
Congestion	
Annual Hours of Delay (AHD)	Travel time above a congestion threshold (defined by State DOTs and MPOs) in units of vehicle-hours of delay.

A robust mix of various measures need to be developed to meet different needs and requirements. Some will be required for federal reporting, for planning, operations, and public reporting. Measures that directly measure congestion are often best for public reporting since these reflect conditions a traveler will encounter. A number of these measures have been adopted for real-time information disbursement.

Chapter 3

Real-Time System Management Information Program

RTSMIP was included in Section 1201 of SAFETEA-LU [6]. The Real-Time System Management Information Program is to provide the capability to monitor in real-time the traffic and travel conditions of the major highways across the U.S. and provide a means of sharing these data with state and local governments and with the traveling public.

3.1 SAFETEA-LU RTSMIP

On August 10, 2005, the President signed into law SAFETEA-LU, the largest surface largest surface transportation investment in the Nation’s history, which guaranteed funding for highways, highway safety, and public transportation totaling \$244.1 billion [7]. It was designed to address modern transportation challenges such as improving safety, reducing traffic congestion, improving efficiency in freight movement, increasing intermodal connectivity, and protecting the environment. The Act promotes more efficient and effective Federal surface transportation programs by focusing on transportation issues of national significance, while giving State and local transportation decision makers more flexibility for solving transportation problems locally.

Targeted investments through SAFETEA-LU include Safety, Equity, Innovative Finance, Congestion Relief, Mobility & Productivity, Efficiency, Environmental Stewardship, and Environmental Streamlining. Within the Congestion Relief area, a new RTSMIP was established to provide all states the capability to monitor, in real-time, traffic and travel conditions and to share that information to

“improve the security of the transportation system, address congestion problems, support improved response to weather events and surface transportation incidents, and facilitate national and regional highway traveler information.”

Section 1201 of SAFETEA-LU established the RTSMIP to combat congestion and provide a common foundation of basic traffic and travel condition information. This information would be made available by the states to improve security, address congestion problems, support improved response to weather events and incidents, and to facilitate comprehensive traveler information. Data exchange format specifications were designed for key interfaces to

enable improved information services from public agencies, private parties designing value-added products, and the general traveling public.

A final Rule for Section 1201 of SAFETEA-LU was published on November 8, 2010, establishing the provisions and parameters for the RTSMIP to be established by State DOTs and their partners. The Program mandated establishment on all Interstate routes by November 8, 2014 and on other metropolitan area routes of significance by November 8, 2016.

3.1.1 Program Requirements

The following requirements were identified for traffic and travel conditions through the RTSMIP program:

1. **Construction activities** – The timeliness for the availability of information about full construction activities that close or reopen roadways or lanes will be 20 minutes or less from the time of the closure for highways outside of Metropolitan Areas and 10 minutes or less from the time of the closure or reopening for roadways within Metropolitan areas. Short-term or intermittent lane closures of limited duration that are less than the required reporting times are not included as a minimum requirement under this section.
2. **Roadway or lane blocking incidents** – The timeliness for the availability of information related to roadway or lane blocking traffic incident will be 20 minutes or less from the time that the incident is verified for highways outside of Metropolitan Areas and 10 minutes or less from the time that the incident is verified for roadways within Metropolitan areas.
3. **Roadway weather observations** – The timeliness for the availability of information about hazardous driving conditions and roadway or lane closures or blockages because of adverse weather conditions will be 20 minutes or less from the time the hazardous conditions, blockage, or closure is observed.
4. **Travel time information** – The timeliness for the availability of travel time information along limited access roadway segments within Metropolitan Areas will be 10 minutes or less from the time that the travel time calculation is completed.
5. **Information accuracy** – The designed accuracy for a real-time information program shall be 85 percent accurate at a minimum, or have a maximum error rate of 15 percent.
6. **Information availability** – The designed availability for a real-time information program shall be 90 percent available at a minimum.

Construction, incident, weather, and travel time information should be reported within 10 minutes of verification within metropolitan area limits and within 20 minutes outside these areas.

3.1.2 Routes of Significance

The RTSMIP rule mandates traffic and travel conditions to be reported not only for highways but also ROS in 2016. However, there is some uncertainty on the definition of a ROS. The law does not provide specific guidelines but instead gives states the opportunity to define ROS as appropriate for their jurisdiction. Part 511 of Title 23 of the Code of Federal Regulations (23 CFR 511) [8] designates the RTSMIP and provides the following ROS guidance

“Routes of significance are non-Interstate roadways in metropolitan areas that are designated by States as meriting the collection and provision of information related to traffic and travel conditions. Factors to be considered in designating routes of significance include roadway safety (e.g., crash rate, routes affected by environmental events), public safety (e.g., routes used for evacuations), economic productivity, severity and frequency of congestion, and utility of the highway to serve as a diversion route for congestion locations. All public roadways including arterial highways, toll facilities and other facilities that apply end user pricing mechanisms shall be considered when designating routes of significance.”

Further, the RTSMIP rule designated “Metropolitan Areas” to mean

“geographic areas designated as Metropolitan Statistical Areas by the Office of Management and Budget with a population exceeding 1,000,000 inhabitants.”

The current standards were adopted in 2010 [9] and provide a single set of geographic delineations for the Nation’s largest centers of population and activity. These metropolitan areas are defined for statistical purposes and denote an area containing a large population nucleus and adjacent communities with a high degree of integration with that nucleus.

The 2010 standards resulted in new Metropolitan and Micropolitan Statistical Areas delineations in February 2013. The new delineations resulted in 51 metropolitan areas with populations greater than one million, including Las Vegas in Nevada. Each of these are then required to identify non-Interstate roads that should be included as a ROS thanks to meeting some significance criteria as agreed upon by the state DOT and partners.

3.2 State Examples

Each state is required to develop a plan to meet reporting requirements for RTSMIP. This plan should be customized to meet the unique needs of each state and the population it serves. In preparation for the 2014 highway and eventual 2016 metro implementation deadlines, many states have been actively engaged in this planning process. As guidance for states with less mature programs, FHWA hosted a webinar in May 2014 to highlight various state efforts and techniques to meet the RTSMIP requirements [10].

3.2.1 Kansas

In the Kansas Division Office they recognize the great progress in real-time management today versus 5-10 years ago. They avoid getting bogged down in too fine level of detail and instead emphasize a process that is consistent and progresses toward the 2016 deadline. They considered ROS to be roadways of similar importance to interstates. They used a network screening process using the following criteria (Table 3.1) to generate a preliminary list of candidate routes.

By considering various factors, a list of potential ROS candidates are generated which satisfy at least one of the meaningful criteria. They then plan to monitor these routes over the next two years to be ready to select the ROS and provide data in Nov. 2016.

Table 3.1: Kansas Key Factors for ROS Screening and Identification

Roadway safety through crash rates
Congestion severity and frequency
Economic productivity through rates of national and state freight
Value as an evacuation or diversion route

Table 3.2: California ROS Implementation Timeline

05/30/14	Provide contact information of the individual/individuals that will assume responsibilities regarding ROS.
09/30/14	Provide a list of proposed ROS and demonstrate how each ROS meets or will meet the criteria.
06/30/15	If criteria for proposed ROS cannot be met prior to deadline, then roadway will not be given consideration.
06/01/16	Local or regional agency must share the strategic plan for Accuracy and Availability with Caltrans.
11/08/16	Provide traveler information for the identified ROS approved by FHWA.

3.2.2 California

As a large state with six metropolitan areas with over one million, the California FHWA Division has been actively working on RTSMIP since early 2013. They assess the accuracy requirement for the data the public sees (online or on the road) for lane closures. They use a required notification system for construction personnel which consists of two reports:

- “Event Start” – when a cone is placed down on the road, a call must be made to a transportation management center (TMC).
- “Event End” – when the cones are picked up and lane is open to traffic, a call must be made to the TMC.

Accuracy was assessed based on all proposed and planned lane closures either through permits, construction, or maintenance. If the Event Start and End calls were received for a planned closure, it was considered an accurately statused closure, and if only one of the two calls were placed then it was non accurately statused. The accuracy was the total number of accurate statuses divided by the total number of statuses and was 91% for all CA districts combined.

In addition, CA had a timeline in place to address ROS as given in Table 3.2. What is noteworthy in their timeline are the second and third stages. Candidate ROS are proposed based on the Program criteria. However, only those candidates which will be able to meet the Nov. 2016 deadline in terms of the six requirements are retained for further consideration. This practical approach suggests that ROS should only be routes that can be effectively monitored without any major efforts. This means that the areas that are currently under observation now are likely to be the RTSMIP ROS in 2016.

3.2.3 Tennessee

The Tennessee FHWA Division office noted that the RTSMIP rules were equivalent to basic user needs and asked themselves three basic questions

- Can our systems meet these needs?
- Do we need to specify interface control?
- Do external users have access?

These questions in turn lead to a prioritized deployment plan by first identifying gaps and determining where equipment such as cameras, speed or travel time detectors, or dynamic message sign (DMS) might be required. These gaps can then be aligned with other construction projects. The RTSMIP also ties directly into other programs; incident detection as part of their Strategic Highway Safety Plan and traffic, closure, and incident information can be paired for business performance management and quantification of improvement investments.

Tennessee currently operates the TNSmartWay brand in order to provide a single source of external information. The service provides both web and mobile app interfaces, statewide 511 and HAR, DMS information, as well as twitter and RSS feeds. All “events” (incidents, lane closures, etc.) are latitude and longitude encoded and provided as map overlays. Data is provided by various sources such as traffic cameras, speed detectors, public reporting of incidents, and informal data collection from TDOT personnel on their commutes. They meet the 90% availability rate through their contract with their ITS provider. In this case, only verified incidents are reported and can be monitored based on timestamps.

Although operating a very modern transportation communication system, they do have areas for improvement. They needed to identify gaps for speed detection and travel time calculation. They note travel times and speed are a concern since probe runs would be costly and are looking to evaluate commercial data sources. They are also hoping to provide simple information exchange protocols for interoperability with their local partners.

3.2.4 North/West Passage Coalition

The recent North/West Passage Coalition conformance report [11], highlights efforts through eight states, including Washington, Idaho, Montana, Wyoming, North Dakota, South Dakota, Minnesota, and Wisconsin, to meet the RTSMIP requirements. Along the corridor, the three metro areas considered for ROS are Seattle, Minneapolis-St. Paul, and Milwaukee.

In Seattle, Washington State DOT will define their ROS network based on AADT, freight use, long range transportation plans, NHS designation, emergency or alternate routes, and other factors. The candidate road segments include 15 state routes, West Seattle Bridge, and US 2 for 17 total ROS. The same criteria was used by Minnesota DOT to identify candidate non-interstate routes for travel time coverage in the Twin Cities Metro Area. In this case, five US highways and seven state highways make up the list of 12 ROS candidates. The Milwaukee Metro Area had three US highways and four state highways identified as candidate ROS. In addition to the previously mentioned factors, these ROS were selected using the OSOW priority network and Connections 2030 Corridors programs.

Along the North/West Passage Coalition, the ROS are almost exclusively on highway road segments where loop and other mature sensors are able to provide travel time information.

Major arterials did not seem to be a concern for meeting the 2016 rule, likely due to difficulty producing travel time measurements in stop controlled traffic.

3.3 Probe Data Services

With the ubiquity of modern GPS devices, either stand-alone, in-vehicle, or in mobile phones, has given rise to a new type of user supplied data collection. Probe data is obtained from GPS devices silently while navigation is in use. Using GPS, it is possible to geo-locate the device and determine the roadway section it is traversing as well as measuring speed. The advantage of probe data is that users provide the information freely while navigating the entire road network. There are no additional sensors to install and information can be obtained over the entirety of the network. The same probe system works just as well on highways as arterials.

3.3.1 Floating Car Data

Researchers have used probe (floating car) data to estimate travel time in the same way a professional probe vehicle on the road can measure time directly. In 2011, the technical and institutional issues associated with the use of private sector probe data for public sector performance management of congestion was studied [12]. This report noted the main concern was the “blending” of traffic data between real-time measurements and historical statistics but concludes that “what is most important is the accuracy of the end product (i.e., average travel times and speed)” which can be assessed via quality assurance methods.

Probe data is now mature and in fact is used as the primary speed data source for the annual Urban Mobility Report by the Texas A&M Transportation Institute (TTI) [13]. Many states have initiated feasibility studies for the use of probe data and validated travel time accuracy to within a few minutes during typical flow and able to distinguish more congested situations [14]. The I-95 Corridor Coalition has performed large-scale deployment of probe data and provided significant documentation on data validity [15] and guidelines to evaluate the accuracy of this data [16].

More accurate travel times can be obtained by direct travel time measurement using Bluetooth systems. These systems perform re-identification of vehicles as they travel a road network based on the Bluetooth ID similar to how a license plate recognition system operates. The Bluetooth communication protocol provides unique identification for very accurate travel times. However, these systems only work on the small portion of vehicles that have Bluetooth enabled and still require base stations installed at critical locations along the transportation network which could become complex.

In addition, social media sites and apps have gained prominence in the mobile era. Now more than ever, individuals are willing to share information for the greater good. Services such as Google Maps [17], Waze [18], and HERE by NAVTEQ [19] all provide probe data. Additional information besides speed and location data have made these systems popular for advanced route navigation. The systems tie into various data streams to obtain information about construction, incidents, locations of speed cameras or police officers. Users can personally upload information to the system as they are encountered for the fastest possible notification time. The large user base and up-to-date information often outperforms more

Table 3.3: Comparison Between TMC and XD Road Segments for Nevada

	FRC	TMC Miles	XD Miles
1	Interstate	1293	1305
2	Freeways & Expressways	3798	4111
3	Major Arterial	2540	4591
4	Minor Arterial	456	518
5	Major Collector	134	211
6	Minor Collector	37	57
7	Local	1	5
	Total Miles	8258	10798
	Total Centerline Miles	4145	5399
	Total Count	5008	13634

traditional data streams from TMCs which have delay before getting to the public – either through dissemination channels or aggregation periods.

For near-term traveler information goals, private probe vehicle data is significantly less expensive to install and maintain than traditional fixed point detectors since it provides immediate coverage of a region’s major roadways. [20]. However, this type of data is not suitable for traffic management applications which require more than speed and travel times.

3.3.2 INRIX

One of the more popular providers of private probe data is Inrix [20]. They provide solutions for Nevada and the country as a whole. The wide-view this affords improves the ability to coordinate with neighboring states and could actually improve NV in-state operations. Their current technology is almost exclusively probe data with little reliance on ITS infrastructure. Early incarnations of their system needed more traditional TMC ITS data because of lower penetration rates.

The data they provide comes in one minute increments and has metadata attached to indicate how it was collected. Data can be directly

1. measured from probe vehicles,
2. be based on historical information, or
3. be a fusion between measured and fusion.

Their propriety algorithms decided which scheme to use based on data availability and reliability.

The system uses the standard traffic message channel (TMC) roadway segment definition as well as their own open XD standard. The XD standard utilizes higher resolution segments with a maximum length of 1.5 miles for finer detail in analysis. A comparison between traditional TMC and XD segments in Nevada is provided in Table 3.3 and highlights the high resolution coverage from INRIX. Integration of TMC or XD segments will require some effort to integrate with NDOT referencing schemes through a roadway mapping table.

The Inrix service is highly customizable. They provide access to data as well as a number of APIs for map overlays as well as analysis. The four main data layers that are available

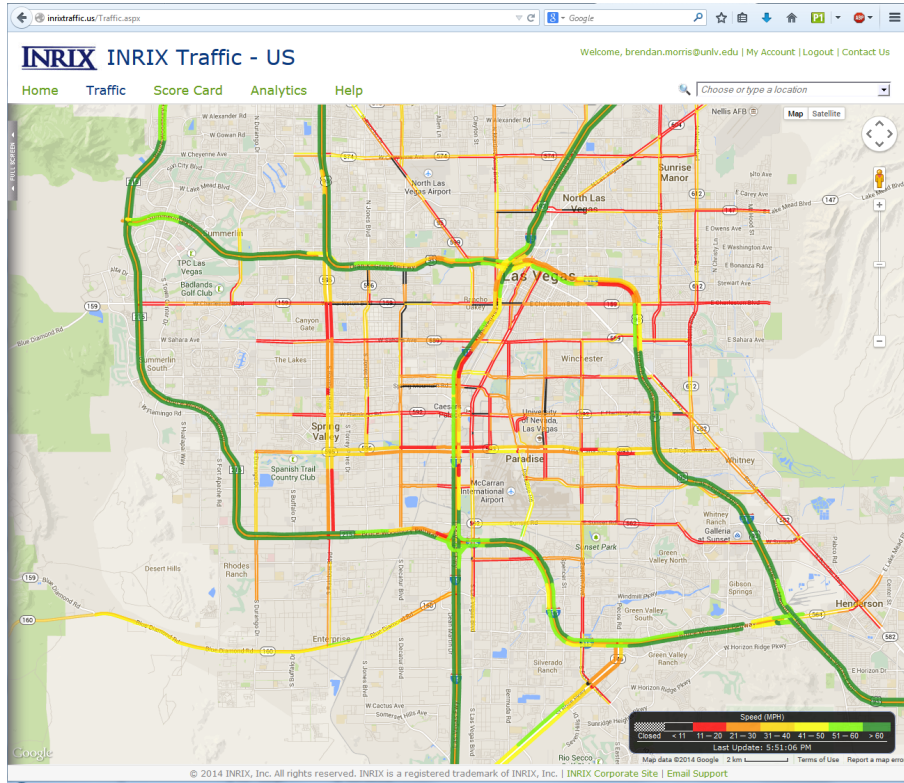
are Speed, Incident, Weather, and an Analytics Suite. The Analytics Suite is hosted by the University of Maryland and provides advanced analysis of the Inrix data. Example analyses are bottleneck studies and calculation of user delay costs.

There is a free site available for all public agencies

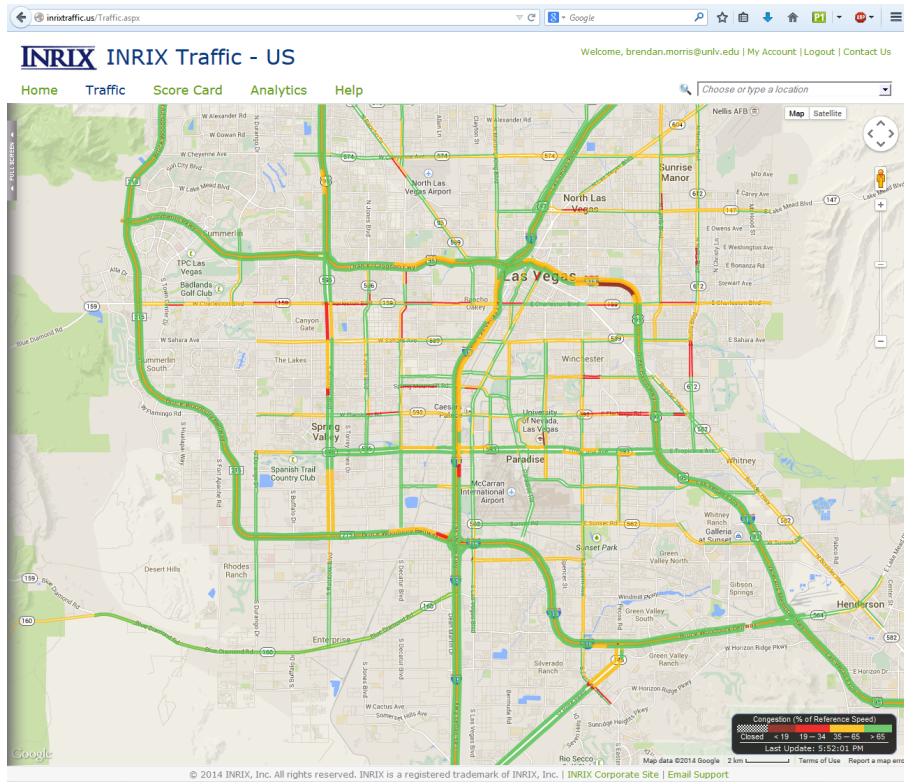
<http://Inrixtraffic.us>.

While this provides access to the entire United States, most coverage in Nevada is along the major Interstate highways. Las Vegas area is well represented as shown in Fig. 3.1. In addition to the highways, data is available along major arterials which is currently missing through the FAST Dashboard. Unfortunately, Reno and Carson City do not have arterial coverage limiting this system's usage to Southern Nevada. However, there is the possibility for expansion into Northern Nevada as device penetration and usage increases.

It should be noted that private sector probe data is best suited for travel times and speeds on highways and major arterials which are best suited for real-time traveler information. More advanced traffic management and control applications which require traffic flows, lane occupancy and detection data will need to utilize public sector sensors in the near term [20]. Therefore, probe data should be considered a complementary data source rather than a replacement.



(a) Speed



(b) Congestion

Figure 3.1: Inrix coverage maps for Las Vegas. Note that major arterials are covered by the probe data.

Chapter 4

Nevada RTSMIP

Nevada's ITS infrastructure has consistently been on the forefront of national practice with a robust network of sensors and management centers running 24/7. This network of high speed fiber communication between field sensors (microwave radar) and traffic cameras provides dense coverage of major metropolitan areas and has the state well positioned to meet all the RTSMIP requirements.

4.1 Interstate Highways

In early 2014, Nevada began RTSMIP compliance efforts by assessing the state's capabilities at gathering and disseminating data in the four areas of construction, incidents, weather, and travel time information with emphasis on the interstate highway system. The state either met or exceeded the reporting requirements in each area.

Construction activities are managed and reported directly to NDOT personnel. The information is provided to TMC operators who upload the data to various reporting channels such as the state 511 system, nvroads.com, bugatti.nv.fast.org FAST dashboard, and email notifications. In addition, TMC operators use the traffic camera network to actively monitor construction zones for detailed traffic updates.

In a similar manner, Incident activities are handled by TMCs. Specific incident information can be obtained through various means. Field observations can be reported by law enforcement (NHP, LV METRO), freeway service patrol personnel, other initial response vehicles, and through notification by the general public. In addition, more technological identification methods are used. Side-fire microwave Radar detectors measure speed along highways. An unusual or unexpected slowing may indicate an incident which can be verified using traffic cameras. Incidents are then reported through the 511 channel, nvroads.com, bugatti.nv.fast.org, through DMS and travel time specific signs, as well as email updates and highway advisory radio (HAR). The collaborative process and multiple distribution channels exceeds RTSMIP regulations.

Weather observations is another area where Nevada excels. Information is reported by the previously mentioned parties as well as maintenance operators and TMCs are able to use the same channels for dissemination. In addition, a number of road weather information system (RWIS) stations are installed throughout Nevada (mostly in the North) that help with rain, snow, and wind warnings. Weather information is also obtained through partnerships with

meteorologists through the MXweather Synder Electric agreement and using the National Weather Service Radar storm tracking and predictions.

Finally, travel time information is available in Nevada by using the ITS sensor network. The side-fire Radar detectors that are instrumented on highways give speed and flow information which are tied into the Freeway Management System (FMS). Using these speed measurements, travel time estimates are computed along various important points and provided to the public on DMS and travel time signs. Arterial travel times are more difficult to obtain because of limited sensors and because of stop controlled devices. Along arterials, travel time can be manually determined by visual tracking of vehicles through a corridor camera view. However, this manual process takes time and effort so a more automated process is desirable. More modern technologies such as Bluetooth sensors and GPS probes have recently been explored. Bluetooth travel time systems (BlueToad) have been tested in limited fashion in Las Vegas with some success. RTC Paratransit GPS provides data that could give arterial travel time with data by expanding to more vehicles such as on bus routes.

Nevada has a robust system in place for the collection of data and for addressing the information needs outlined by RTSMIP. The ITS infrastructure and communication protocols in place provide adequate coverage of Nevada as a whole with superior coverage in major population centers. The main area that is lacking is in the difficult area of arterial travel times. It may take significant effort, manpower or new ITS infrastructure, to provide reliable travel times on non-highway roadway sections in the short term without the use of private data collection services.

4.2 Metropolitan Areas

Figure 4.1a gives the population distribution by county in Nevada. Only the Las Vegas-Henderson-Paradise metro area fits the RTSMIP designation with a 2010 population of 1,941,269 people. The two other major metropolitan areas in Nevada are Reno (425,417) and Carson City (55,274). Using Nevada State Demographer projections [21], even in 20 years, neither Reno or Carson City would fall under the rule (Figure 4.1).

4.3 Routes of Significance

The main uncertainty in the RTSMIP program is in the definition of ROS. Nevada's RTSMIP Kick-Off Meeting with FHWA in January 2014 recommended using a collaborative process between NDOT and FAST to determine ROS in compliance with 23 CFR Parts 420 and 940 by the beginning of 2016. The suggestion was to develop a preliminary list of ROS from stakeholders such as Clark County and the TIM Coalition. However, the final ROS should be based on traveler information, where drivers go.

Following the Kansas example and utilizing 23 CFR 511, the Las Vegas road network can be screened using various importance criteria related to roadway use. Using this guidance, the following criteria were utilized to screen the Valley road network and identify potential ROS:

- Speed - belief that higher speeds are more important.
- Daily traffic - belief that number of vehicles is important.

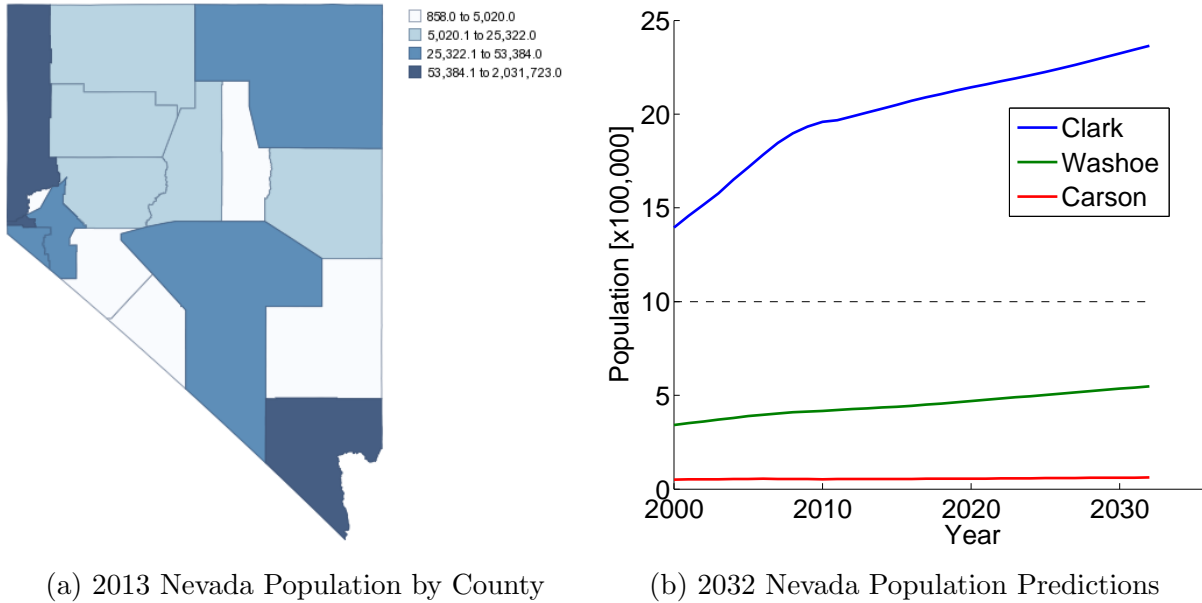


Figure 4.1: Nevada State Population Information

- Major roads - define large cross cutting roads.
- Evacuation routes - non-highway routes out of the city.
- Sensor coverage - pragmatic definition based on available coverage which indicates importance.

4.3.1 Network Screening

Using Clark County GIS data from the GIS Management Office [22], the Las Vegas road network was screened using the selection criteria highlighted in Table 4.1 to determine candidate ROS. Fixed attributes, Major Road and Evacuation Routes, were determined by examining the map and FRC designation for each roadway segment. The dynamic attributes were also evaluated for each road segment. Only segments that had average speed greater than 30 MPH and VMT greater than 10,000 were considered. Figure 4.2 highlights the meaningful roads after screening by the criteria. Using the speed criteria, most of the Las Vegas Valley is eligible while the VMT criteria significantly reduced the possible routes. In addition, the locations of sensors (green circles) and their coverage can be seen in purple.

For arterials, only cameras are available for traffic observation. FAST has experimented with other data collection techniques such as Bluetooth stations for travel time measurement but without much success to date. While the traffic cameras do not directly and automatically provide traffic time, they are well suited for this type of analysis. Visual inspection can be used to follow platoons of vehicles along corridors to compute travel time. In addition, the cameras are able to provide information on construction, incidents, and weather making it an ideal multipurpose sensor. However, we recommend developing clear practices for travel time estimation. This could either be from periodic intervention manually or through the development of image and video processing to help automate the process.

Based on these coverage maps (Fig. 4.2), a set of 17 potential ROS were designated as provided in Table 4.2. The major ROS were selected to span the various cardinal regions in

Table 4.1: Network Screening Criteria for ROS

Criteria	Comment	Application
Speed	Higher speeds are more important.	Avg. speed > 30 MPH.
Daily Traffic	Greater number of vehicles is more important	Daily VMT > 10,000.
Major Road	Only consider large cross cutting roads.	Consider FRC Major Arterial
Evacuation Routes	Require non-highway routes out of the city center.	ROS must span the highway system (i.e. should be able to exit from highway and travel until reaching another highway).
Sensor Coverage	Existing sensors indicate routes of importance.	Sensor must be within defined distance of a sensor "view".

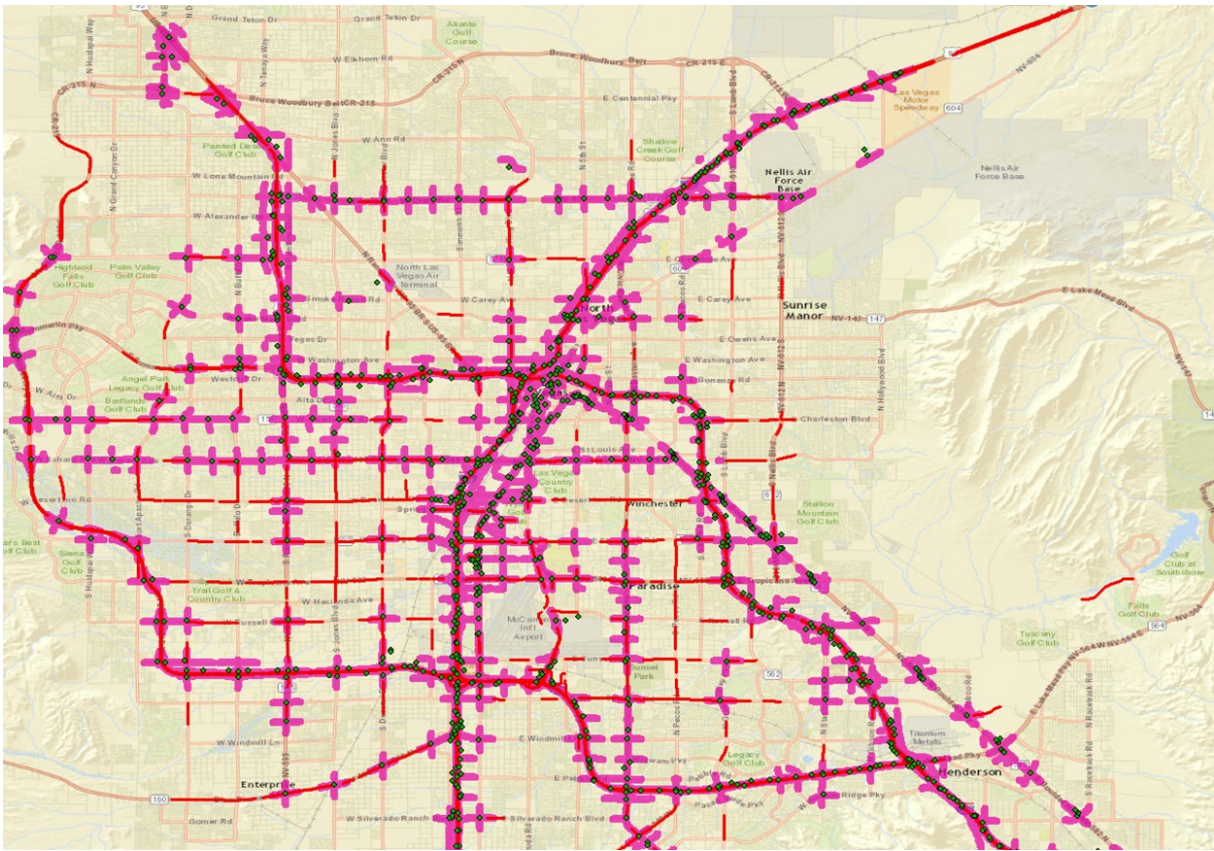
Table 4.2: Las Vegas Routes of Significance
(Green Indicates Need for Major Sensorization)

Route	Dir.	Route	Dir.
1 (SR 573) Craig Rd	E-W	9 (SR 582) Boulder Hwy.	N-S
2 (SR 159) Charleston Blvd.	E-W	10 (SR 595) Rainbow Blvd.	N-S
3 (SR 589) Sahara Ave.	E-W	11 (SR 607) Eastern Ave.	N-S
4 (SR 593) Tropicana Ave.	E-W	12 (SR 612) Nellis Blvd.	N-S
5 (SR 592) Flamingo Rd.	E-W	13 Martin Luther King Blvd.	N-S
6 (SR 160) Blue Diamond Rd.	E-W	14 Las Vegas Blvd (Strip)	N-S
7 (SR 146) St. Rose Pky.	E-W	15 US 95	N-S
8 Summerlin Pky.	E-W	16 US 93	N-S
		17 CC 215	

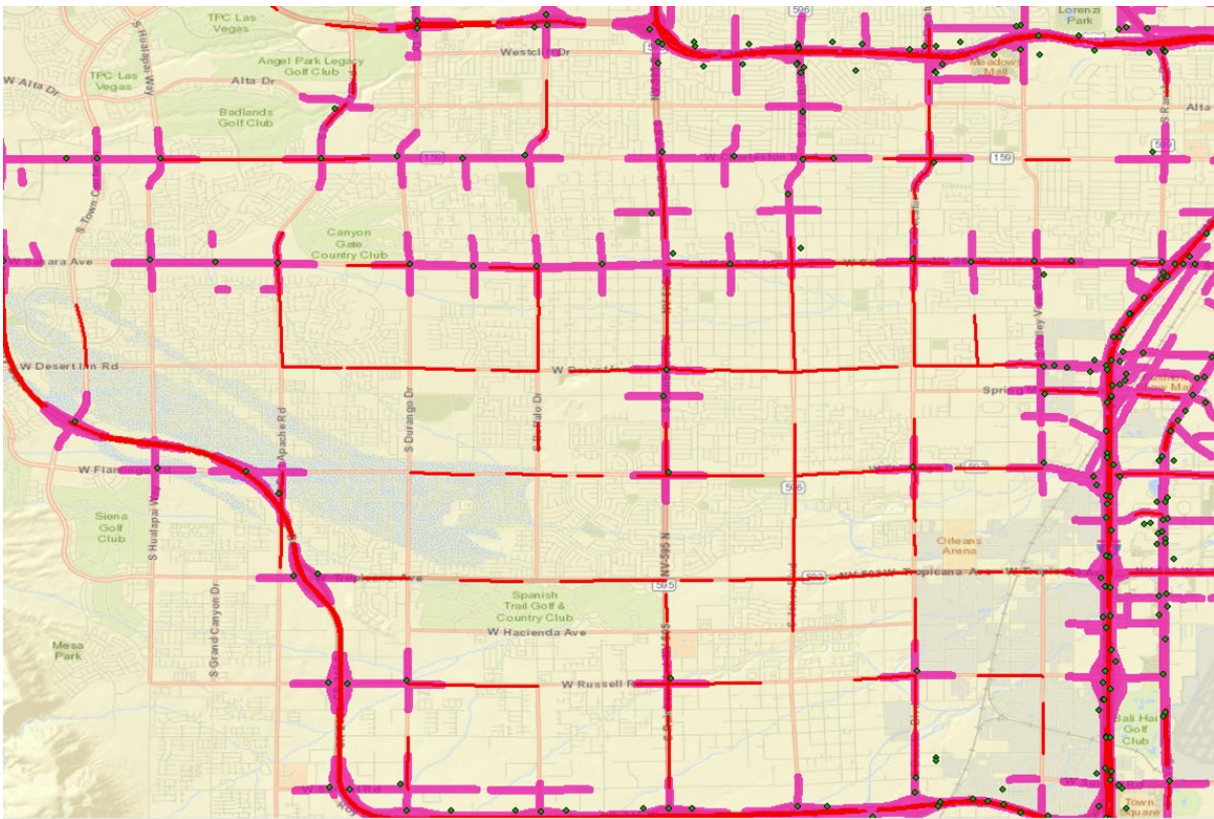
Las Vegas. In the North, Craig Rd. going East-West and Nellis Blvd. and MLK going North-South were identified. In the West, the ROS are Charleston Blvd., Sahara Ave., Flamingo Rd., and Tropicana Ave. are the East-West routes and Rainbow Blvd. is the North-South route. Only Blue Diamond Rd. and St. Rose Pky., both going East-West, were identified in the South. Finally, in the East were Eastern Ave. and Boulder Hwy. in the North-South direction. Additionally, four highways of US 95, US 93, Summerlin Pky., and Clark County 215 are included.

4.3.2 Gap Identification

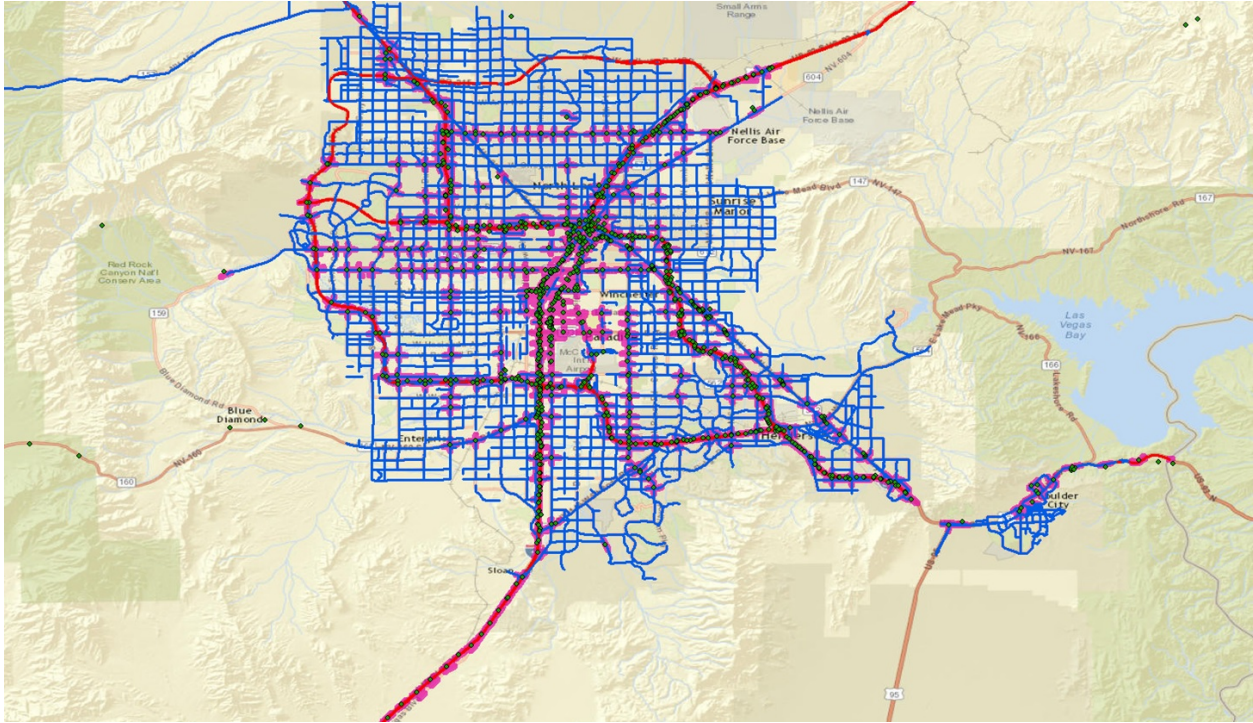
In order to identify gaps, the road network was divided into highways and arterials. Highways are instrumented with Radar detectors for speeds and travel time and cameras to observe congestion while arterials only utilize cameras. Using GIS tools existing sensor coverage was determined using the following parameters:



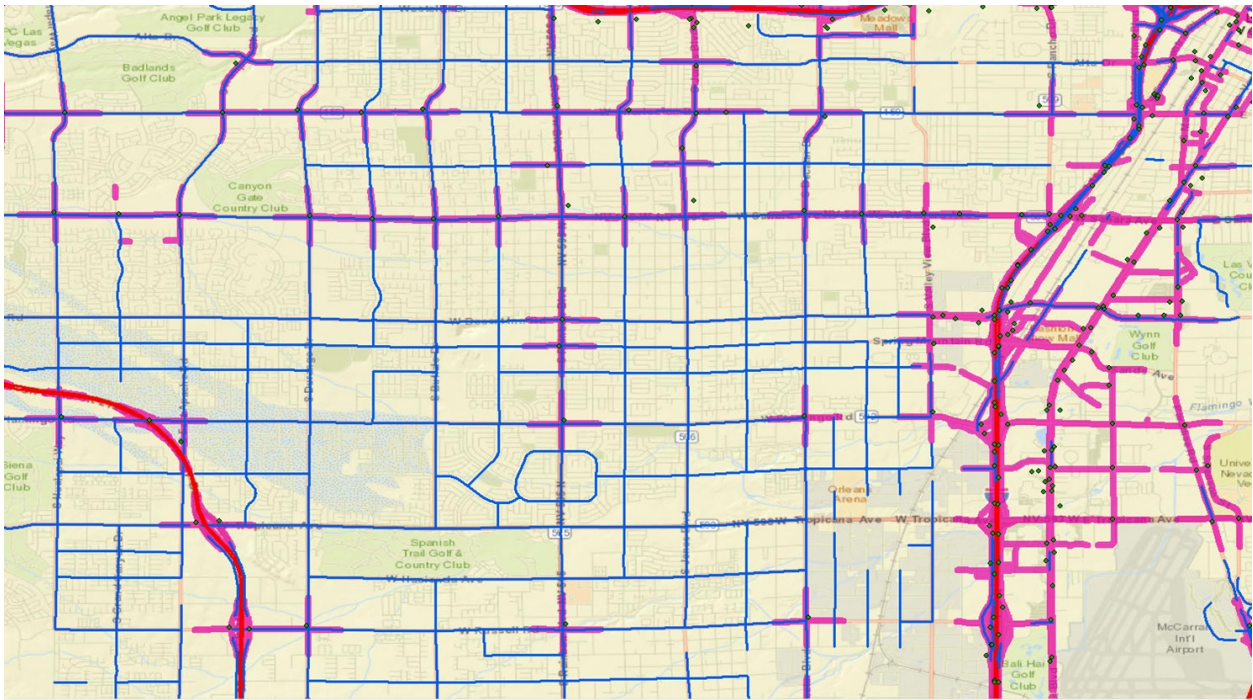
(a) Las Vegas Valley VMT View



(b) Zoomed West Las Vegas VMT View



(c) Las Vegas Valley Average Speed View



(d) Zoomed West Las Vegas Average Speed View

Figure 4.2: ROS Network Screening: GIS maps were used to determine significant routes and gaps along these routes. Purple color indicates coverage area for an existing camera. (a)-(b) Red color denotes $VMT > 10,000$. (c)-(d) Red are highest speed sections > 45 MPH and Blue indicate speeds between 30-45 MPH.

Table 4.3: 23 High Priority Radar Locations for CC 215

	Latitude	Longitude		Latitude	Longitude
1	-115.288851	36.077549	2	115.288851	36.092776
3	-115.295786	36.106194	4	-115.313425	36.118858
5	-115.335286	36.131069	6	-115.341611	36.198517
7	-115.334853	36.212604	8	-115.325526	36.228213
9	-115.325145	36.238587	10	-115.316769	36.24525
11	-115.314961	36.255053	12	-115.322956	36.259431
13	-115.32762	36.268663	14	-115.327144	36.276753
15	-115.318078	36.282547	16	-115.304515	36.280049
17	-115.277389	36.278621	18	-115.237058	36.276122
19	-115.205649	36.276122	20	-115.178523	36.291827
21	-115.150683	36.293968	22	-115.11856	36.290399
23	-115.081441	36.291113			

Table 4.4: 3 High Priority Radar Locations for Summerlin Pky.

	Latitude	Longitude		Latitude	Longitude
1	-115.322718	36.194745	2	-115.307728	36.186893
3	-115.294165	36.179754			

- Radar – 0.5 mile range only highways.
- Traffic Camera – 450 meter viewing range.

Radar Detectors

The highway system in Las Vegas is very well covered with one of over 440 Radar detectors approximately every 0.5 miles. All interstate routes are completely covered and satisfy the RTSMIP requirements. Although four non-interstate highways are in the Las Vegas area, US 93 and I-15 have shared numbering and does not have any data gaps. In addition, US 95 is covered by existing sensors. The side-fire Radar sensors provide speed and flow data which can be used for incident detection and for travel time computation.

The two remaining routes have gaps to be filled by Radar sensors. The list of 23 CC 215 sensor location are presented in Table 4.3. Sensors were spaced along the roadway between S Durango Dr. and Summerlin Pky. for even coverage. Similarly, the length of Summerlin Pky. (between US 95 and CC 215) should be equipped with 3 Radar sensors locations as provided in Table 4.4. In order to meet the 2016 deadline, NDOT should coordinate with Clark County Public Works and the City of Las Vegas in their jurisdictions.

Traffic Cameras

Traffic cameras are a valuable tool for transportation management. They provide operators a visual interface to monitor the road network. The traffic cameras can be used to detect and monitor construction events, weather events, and incidents. They work very well in conjunction with Radar as a verification tool. In addition, traffic cameras can be used as

a travel time tool in non-highway situations by tracking vehicles. Because traffic cameras provide information for all RTSMIP areas, they are valuable investments.

It is important to note that Las Vegas has invested heavily in the traffic camera network with over 500 in the Valley along arterial streets. It is clear that they already provide significant coverage. However, some gaps in coverage along these routes exist. A data gap analysis was performed to make recommendations on locations for new sensor installations along all potential ROS. During gap analysis, no preference was given to roads that were already sensorized.

The VMT and Speed screen maps were used to identify all roads that had large traffic volume and speed. Each criteria was considered separately and gaps were found for installation of cameras. An example of a data gap can be seen in Fig. 4.2b in the top left corner below the Badlands Golf Club along Charleston. The road is marked red for passing the VMT screen but the purple sensors do not cover it. Each gap location was given a priority ranking to indicate how important a sensor would be at the location. The highest priority, Priority 1, was given to a gap that was at the intersection of two major streets both in the NS and EW directions. If the intersection was between a major and minor street, a medium priority 2 was applied. Any intersection of minor streets or non-intersection midblocks were selected as the lowest priority 3. The process was performed for both VMT and Speed. The Speed criteria selected most roads so only the largest roads were used in the gap analysis. The full list of gaps can be found color-coded by priority in Appendix B.

The gap locations provided by the VMT criteria and Speed criteria were combined using a priority mapping function. The final priority p was a combination of the individual criteria priority (p_{VMT}, p_{SP})

$$p = \begin{cases} 1 & (p_{VMT}, p_{SP}) = (1, 1) \text{ or } (2, 1) \text{ or } (1, 2) \\ 2 & (p_{VMT}, p_{SP}) = (0, 1) \text{ or } (1, 0) \text{ or } (2, 2) . \\ 3 & \text{else} \end{cases} \quad (4.1)$$

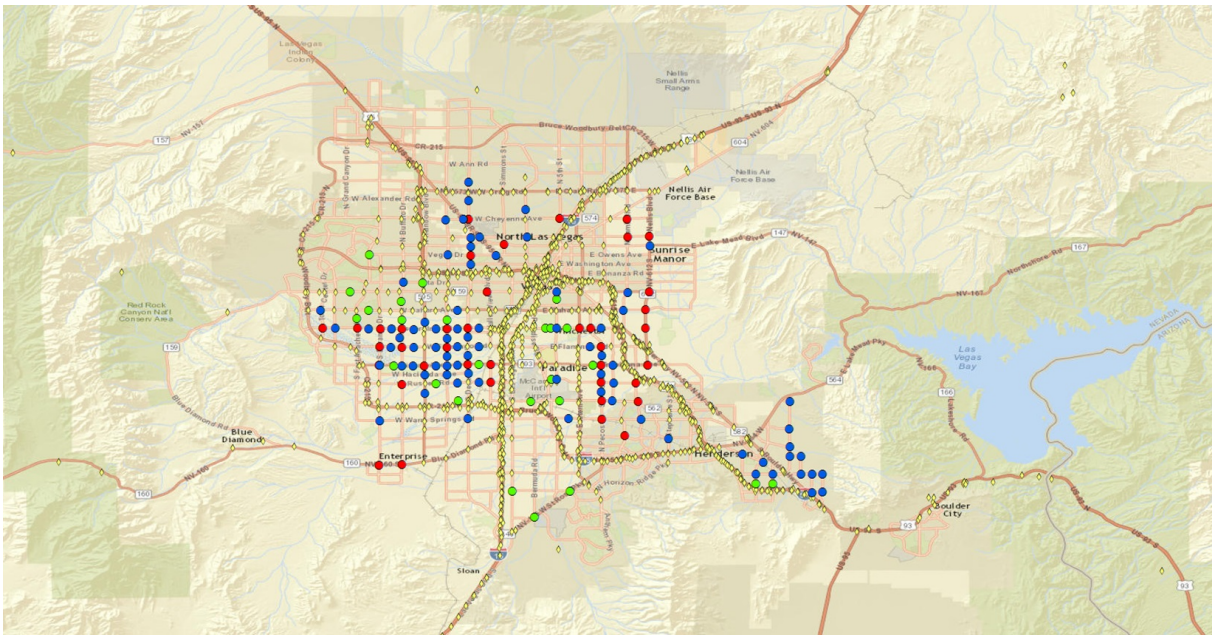
The gap analysis resulted in 144 (39 high) priority locations for dense coverage of Las Vegas with video sensors. Figure 4.3 highlights all the gap locations on a map. The color-code shows the highest priority in red, mid priority in blue, and low priority in green circles. The existing sensors are plotted in yellow diamonds. Notice, the gap locations are designed to provide long coverage between highway segments along major through routes.

Since even the 39 high priority locations is still a large number of installations for the 2016 deadline, a smaller subset of highest priority locations were identified for minimum ROS coverage. The locations highlighted in Table 4.5 are the highest priority installations along existing sensor routes. These 18 locations are the fewest number that could still provide complete ROS coverage of the Valley and meet the reporting requirements.

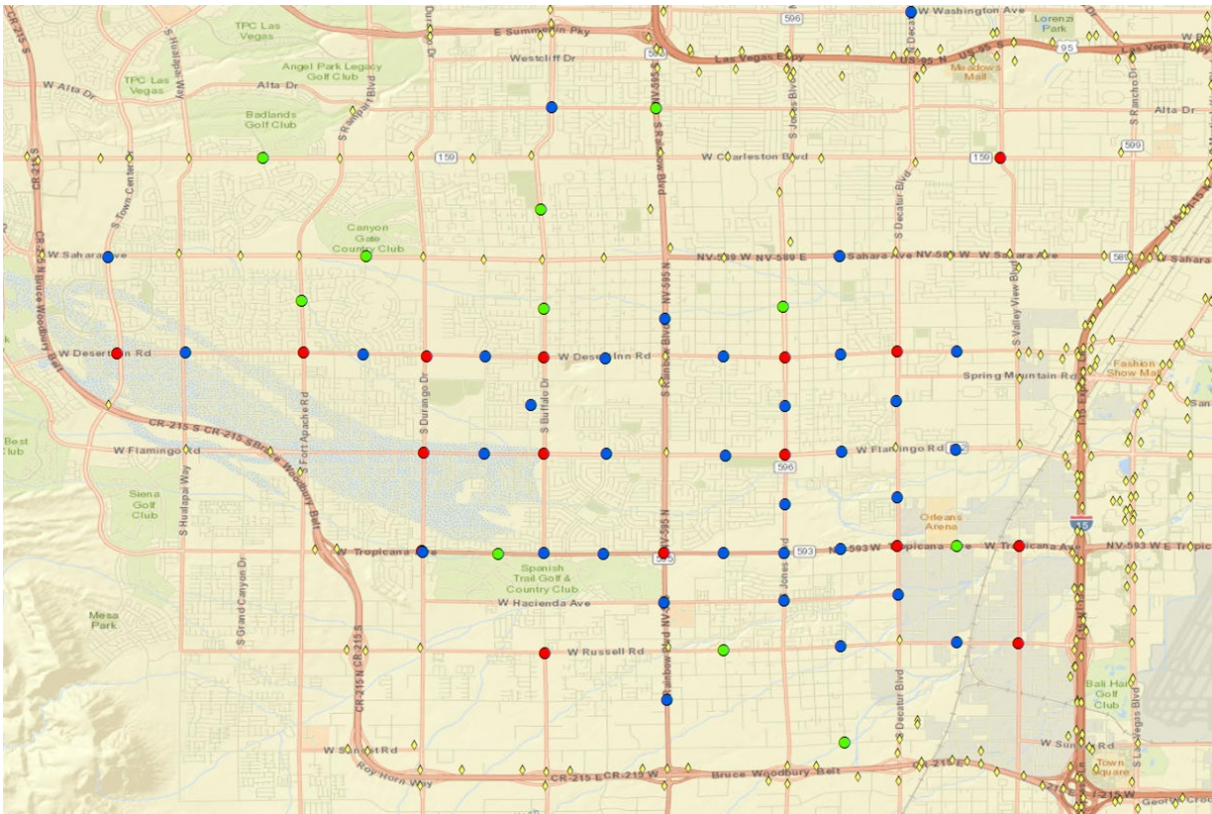
All the gap analysis ArcGIS files are available online at

<http://rtis.oit.unlv.edu/cazzi/indexUI.php>.

In addition, Google Maps Fusion tables were created for interactive browsing of the Radar coverage, Camera coverage, and priority color-coded sensor installation locations for ROS coverage are provided.



(a) Las Vegas Valley View



(b) Zoomed West Las Vegas View

Figure 4.3: Recommended locations for new sensor installations based on VMT, speed, and roadway type color-coded to indicate priority (Red = High, Blue = Medium, Green = Low). In general, higher priority was given to intersections along routes with existing infrastructure to fill small data gaps while lower priority was selected for midblock areas. (Yellow Diamonds indicate locations of existing sensors)

Table 4.5: 18 Highest Priority Camera Locations for Minimum ROS Coverage

	N-S Street	E-W Street		N-S Street	E-W Street
1	S Rainbow Blvd	Edna Ave	2	S Rainbow Blvd	W Tropicana
3	S Rainbow Blvd	W Hacienda	4	S Rainbow Blvd	Patrick
5	S Rainbow Blvd	Alta Dr	6	S Valley View Blvd	W Charleston
7	Apple Dr	W Charleston	8	S Lamb Blvd	E Charleston
9	Nellis Blvd	E Charleston	10	S Maryland Pky	E Charleston
11	S Eastern	E Desert Inn	12	Lindel Rd	W Sahara
13	S Town Center	W Sahara	14	S Lamb blvd	E Sahara
15	Nellis Blvd	E Sahara	16	S Las Vegas	Cactus Ave
17	N Martin L King	Gowan	18	N Martin L King	Carey Ave

Chapter 5

Performance Measurement Research System

A data dashboard was created, similar to the FAST Dashboard - Performance Monitoring and Measurement System (PMMS) [23], with emphasis on RTSMIP analysis.

`http://rtis.oit.unlv.edu/cazzi/indexUI.php`.

This system collects data at the highest temporal resolution (1 minute data) to provide access to the highest fidelity data streams for research and analysis. The FAST Dashboard only provides 15 minute data aggregates which does not always provide sufficient temporal resolution for response. The PMR Dashboard is composed of five major modules:

- database,
- data collection,
- ITS inventory,
- performance measures,
- and visualization and access

with a functional schematic as provided in Fig. 5.1.

5.1 Data Collection

The data collection layer is designed to insert live traffic data into the the PMR database. This abstraction layer requires an interface program which can access a particular sensor and automatically generate the SQL commands to insert into the database. Various data sources can be utilized such as radar sensors, cameras, or even social media.

5.1.1 FMS Radar Data

The main distinction between the PMR and FAST systems is the temporal aggregation period. FAST only provides data at 15 minute aggregates while the PMR system archives at 1Hz. The higher sampling rate was utilized to provide better temporal resolution for analysis. For example, an incident can only be localized within a 15 minute window using FAST while higher resolution data can isolate down to the minute.

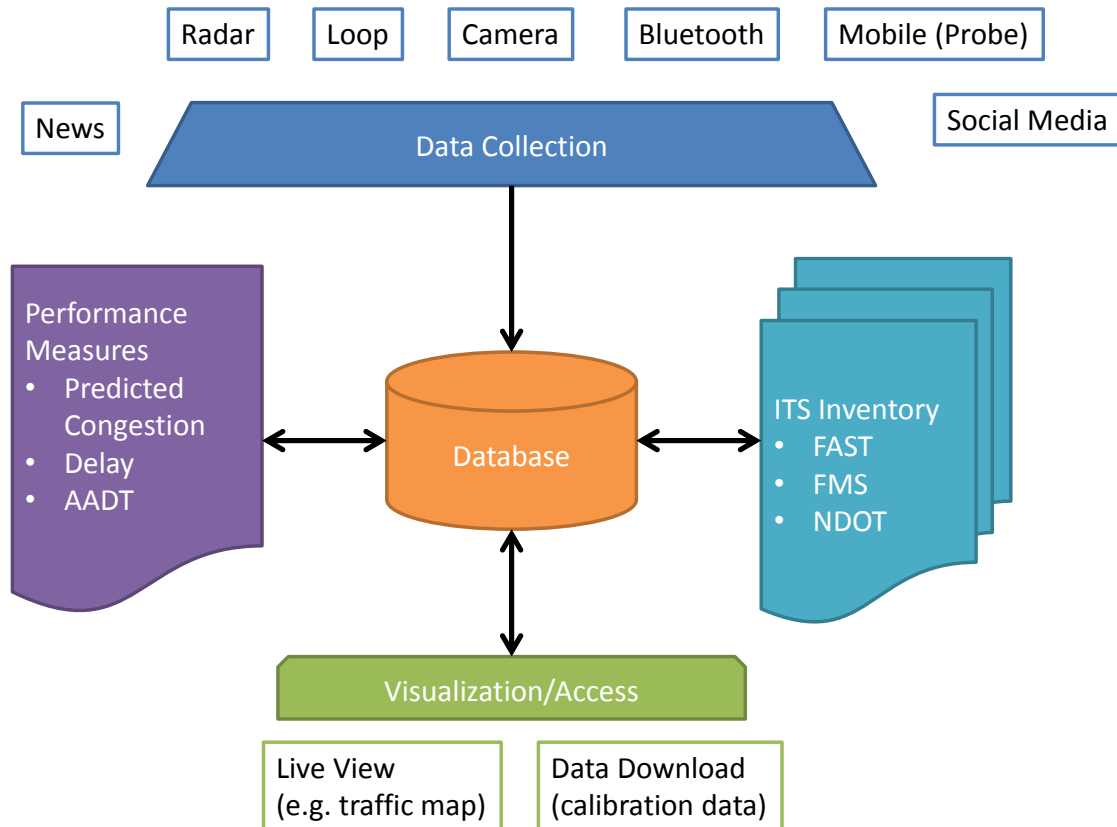


Figure 5.1: Performance Measurement Research (PMR) Dashboard Framework.

The PMR system currently provides access to 1-minute Radar data in Las Vegas. The same Freeway Management System (FMS) sensors are utilized. The FMS system provides an XML interface to the Radar data which is accessible on a FAST FTP site. The following XML files are provided

- **DMSInventoryDistrict1.xml** – Provides metadata for dynamic message signs (DMS).
- **DMSStatusDistrict1.xml** – Provides information of messages on DMS.
- **metadata.xml** – Provides metadata about the sensors, including location in latitude and longitude, name of street location, detector id, etc.
- **realtime.xml** – Provides 1 minute sensor data of lane level vehicle flow, occupancy, and speed.

A python script was created to automatically fetch new measurements every minute. The script accesses the FAST FTP site to download the newest data .xml files and parses the files to extract the measurements for each detector. The script then saves the data in a more accessible format by pushing the data into a specially designed database (Section 5.2). Insertion checks are performed to prevent duplication of data. This can happen if a new measurement file has not been received at the FTP site.



(a) Highway



(b) Intersections

Figure 5.2: Video-based collection through vehicle tracking for highways and intersections. Vehicles are detected and tracked over time (fixed color bounding box) to provide speed and turning movement count information.

5.1.2 Additional Data Sources

Only FMS Radar data has been processed. However, the abstraction layer enables various sensor types to be integrated into the PMR system. Each sensor should have its own separate process to access its data and to push it into the database. This provides a simple diversification procedure where sensors are combined at the data level. Gaps from in the system can then be more easily filled using the appropriate technology.

Current research [24–26] has developed computer vision algorithms that operate on existing traffic cameras to provide highway measurements. This is complementary information to the FMS but provides the advantage of having better area coverage instead of a single “spot”. By using cameras, lane-level measurements of speed and lane changes can be used to augment the existing traffic measures. In addition, many intersections and corridors are equipped with traffic cameras which can be used for arterial measurements which are currently missing. Mid-block (or highway) cameras can do vehicle counts and speed [26] while intersection cameras can provide turning movement counts (TMC) [24]. Example output from video processing algorithms is presented in Figure 5.2.

5.2 Back-End Database

A back-end MySQL database was designed to provide access to historical traffic measurements from any type of sensor that might be incorporated into the system. (At this stage, the only sensor type incorporated is Radar). The database is built around lanes to enable quick access to lane measurements for individual detectors for a given date range. Archival was performed at this resolution to provide the ability to perform lane level analysis and control in the future.

The database is indexed based on date, a detector id, and the lane number of the road. Each sensor measurement is timestamped upon insertion. The timestamp provides a search index and also prevents duplication of data. As described in Section 5.1.1, an improperly functioning sensor might not provide an updated measurement each collection time period resulting in a copy of the previous value.

The full database schema is provided in Figure 5.3. Separate tables were created for each lane (up to seven maximum) to store traffic information of flow, occupancy, and speed for highway segments. The lane tables are linked geospatially to a specific detector and temporally through timestamps. By creating primary-foreign key pairs on detector name and timestamp, the database has savings in terms of storage space since detector locations with fewer lanes do not need to store values for non-existent lanes. The `Detector` table is a fixed size equal to the number of sensors in the system while the `Dates` table increases each time a there is a sensor insertion (this occurs every minute).

In addition, to space savings, the design provides indexing on specific detector id and date range for better performance during retrieval. For a typical query (i.e. for all data from a sensor over a specific time period), only the timestamp and the detector indices are required to parse through the large lane data tables in a single pass.

In order to get a specific date range, the `Date` table is queried for all data between given time period as shown in the following SQL query command.

```
1 SELECT date_index FROM dates WHERE date_time BETWEEN '2014-06-02 14:43:00  
' and '2014-06-02 14:43:59 ' ) AND ( SELECT date_index FROM dates  
WHERE date_time BETWEEN '2014-06-03 14:43:00 ' AND '2014-06-03 14:43:59 ' )
```

A specific detector is isolated by finding its `detector_id` within the `Detectors` table and can be used as a unique index to the lane data tables.

```
1 SELECT detector_index FROM detectors WHERE detector_id = '10_2_268 '
```

An example SQL query is provided below to retrieve a full day's worth of data (all lanes and traffic parameter) from detector id=10_2_268.

```
1 SELECT a.detector_id , c.date_time , b.lane_vehicle_count , b.  
lane_vehicle_count1 , b.lane_vehicle_count2 , b.lane_vehicle_count3 , b.  
lane_vehicle_count4 , b.lane_vehicle_count5 , b.lane_vehicle_count6 , b.  
.occupancy , b.lane_vehicle_speed FROM detectors a, lane1 b , dates c  
WHERE lane1_index_detector = ( SELECT detector_index FROM detectors  
WHERE detector_id = '10_2_268 ' ) AND lane1_index_date BETWEEN (   
SELECT date_index FROM dates WHERE date_time Between '2014-06-02  
14:43:00 ' and '2014-06-02 14:43:59 ' ) AND ( SELECT date_index FROM  
dates WHERE date_time BETWEEN '2014-06-03 14:43:00 ' and '2014-06-03  
14:43:59 ' ) AND a.detector_index=(SELECT detector_index FROM detectors  
WHERE detector_id = '10_2_268 ' ) AND date_index=lane1_index_date
```

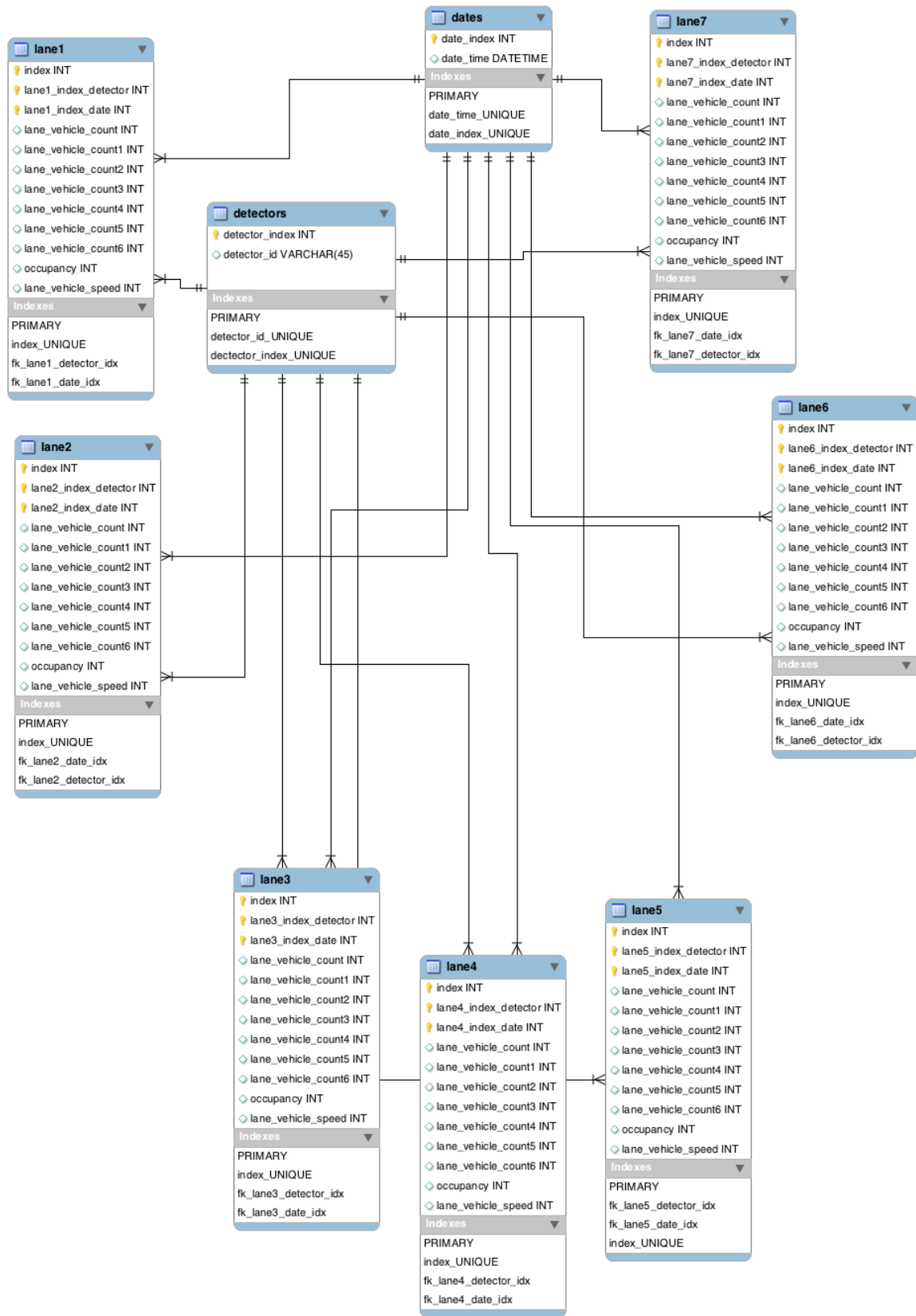


Figure 5.3: Back-end database schema designed for efficient access to lane level traffic measurements.

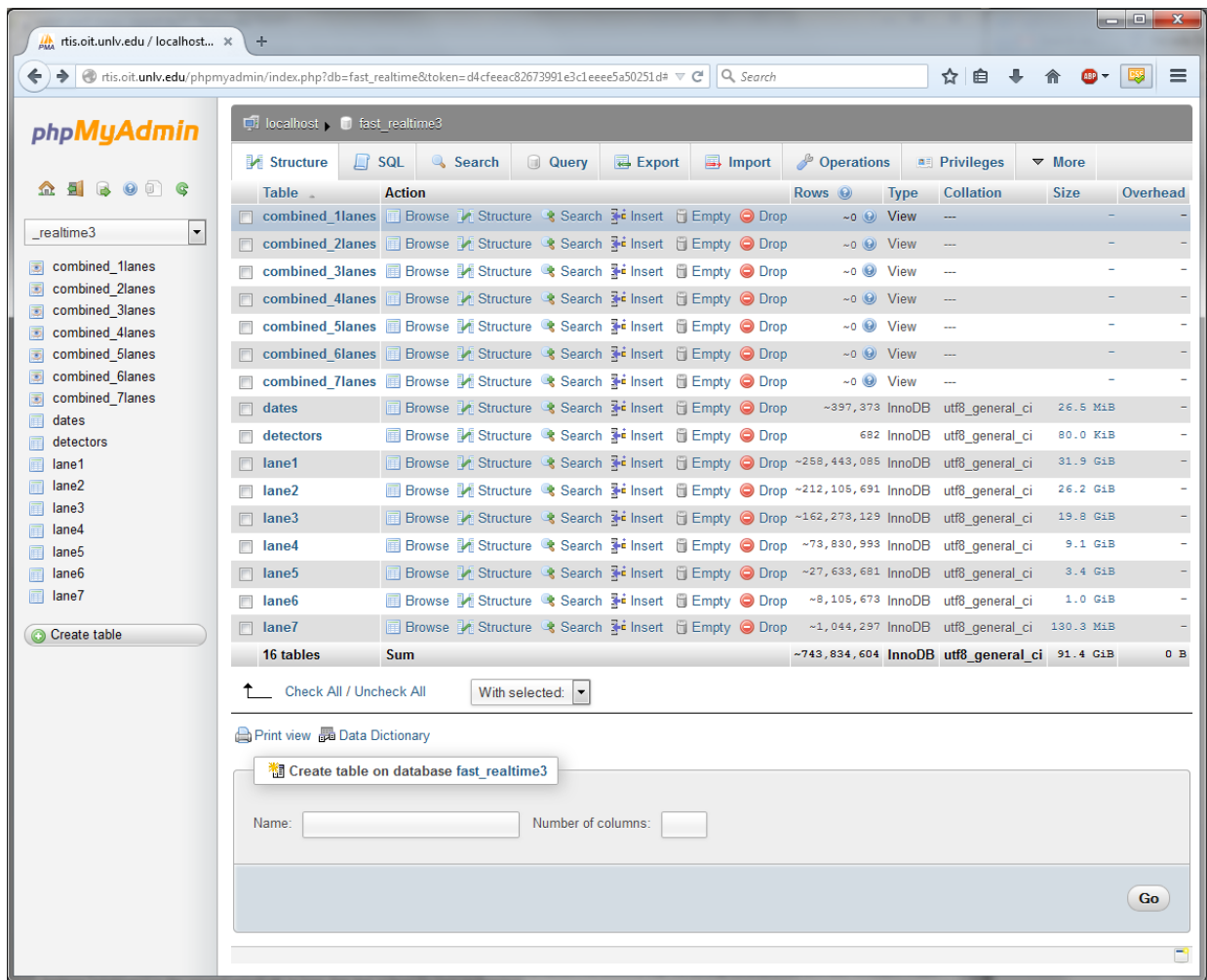


Figure 5.4: Remote database management enabled through phpMyAdmin web interface.

The database can be managed through a web interface at

<http://rtis.oit.unlv.edu/phpmyadmin>.

The web interface uses the phpMyAdmin tool to provide remote access to the database and basic management functionality as shown in Figure 5.4. Through the interface, it is possible to directly issue SQL commands to access and retrieve data as well as view the contents of the database.

Further improvements for the database are required for continued long-term usage. Currently, new detectors can be added to the system automatically, but the addition of new lanes to an existing sensor requires manual intervention. In addition, new tables should be created to handle intersections, e.g. the turning movement counts in each direction. Proper database maintenance is also required periodically to keep data time ordered for best performance.

Table 5.1: PMR ITS Inventory

System	Type	Count
FMS	CCTV	526
	DMS	96
	Detector Station	448
	Ramp Meter	70
	RWIS	12
	HAR	1
FAST	Detector	480

5.3 ITS Inventory and End-User Access

In order to use the PRM system, an inventory of ITS devices was needed to populate the database and a visualization interface was required to access the data. While the phpMyAdmin web interface could be utilized, this required more expert knowledge of databases and the sensors. A map-based web portal was built to provide an intuitive wrapper for data access, located at

<http://rtis.oit.unlv.edu/cazzi/indexUI.php>.

A user could see the location of various ITS devices on a map and extract data without having to perform complicated database SQL commands.

5.3.1 Device Inventory

The ITS device inventory from Southern Nevada was integrated into the PMR site. The inventory consisted of all the FMS devices which included Detector Stations, Ramp Meters, CCTV, DMS, RWIS, and HAR locations as well as devices from FAST through the Dashboard. Although the FAST and FMS Detector information reference the same physical devices, the FAST device list was used as the primary Detector source. Due to visualization constraints through the FMS system, the coordinates of a sensor might not actually reflect the true locations. The FAST data was corrected to reflect the true locations. In addition, FAST maintains a more up-to-date list of sensors as they are installed. Table 5.1 provides a summary of the devices included in the PMR system.

5.3.2 Visualization Interface

The PMR homepage provides an overview of all the sensors in the system using Google Maps API (Figure 5.5). By clicking on a particular sensor icon on the map, the device info, such as the device type, identification numbers, location, etc., are provided in a table below the map for reference (Figure 5.6). This basic information is useful for correlation with other systems such as FMS and the FAST Dashboard.

Further information about the Radar detectors are obtained through a separate “Detectors Info” tab. Detectors are logically grouped and organized for direct access to detector

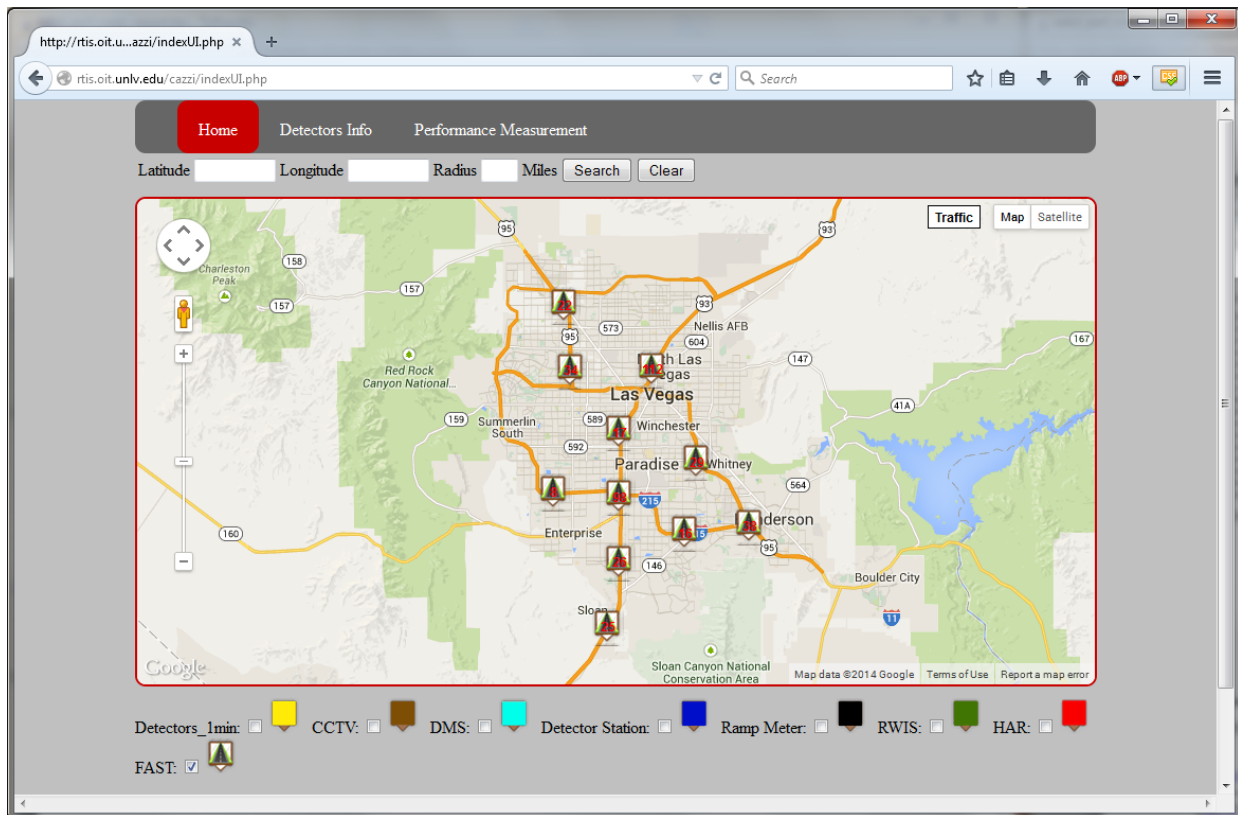


Figure 5.5: Map View of ITS Inventory: Includes all FMS sensor data and FAST detectors.

measurements. The PRM system utilizes FAST’s corridor definitions to match the Dashboard. Sensor data can be downloaded as a comma separated value (CSV) file by selecting the appropriate search parameters:

- Freeway: the highway number and direction
- Corridor: the subsection of the highway between exits
- Detector: the detectors within the road section
- Lanes: the lanes of the highway
- Date and Time: the range of dates and time to consider.

As shown in Fig. 5.7, the system is designed to actively update the map visualization during the selection process. After selecting a Freeway and Corridor, the highway section is highlighted in blue with end points denoted by markers. The map is zoomed to optimize the corridor view. The detectors are placed on the map after selection and all the data can be extracted for the selected lanes over the given date range. All available data is returned in a CSV file at 1 minute resolution. This is the highest resolution available for the Radar data. This resolution is important for fine-grained and detailed analysis of events. The 15 minute timescale provided by the FAST Dashboard does not allow for precise temporal localization of events which is necessary to meet the 10 and 20 minute deadlines imposed by the RTSMIP program.

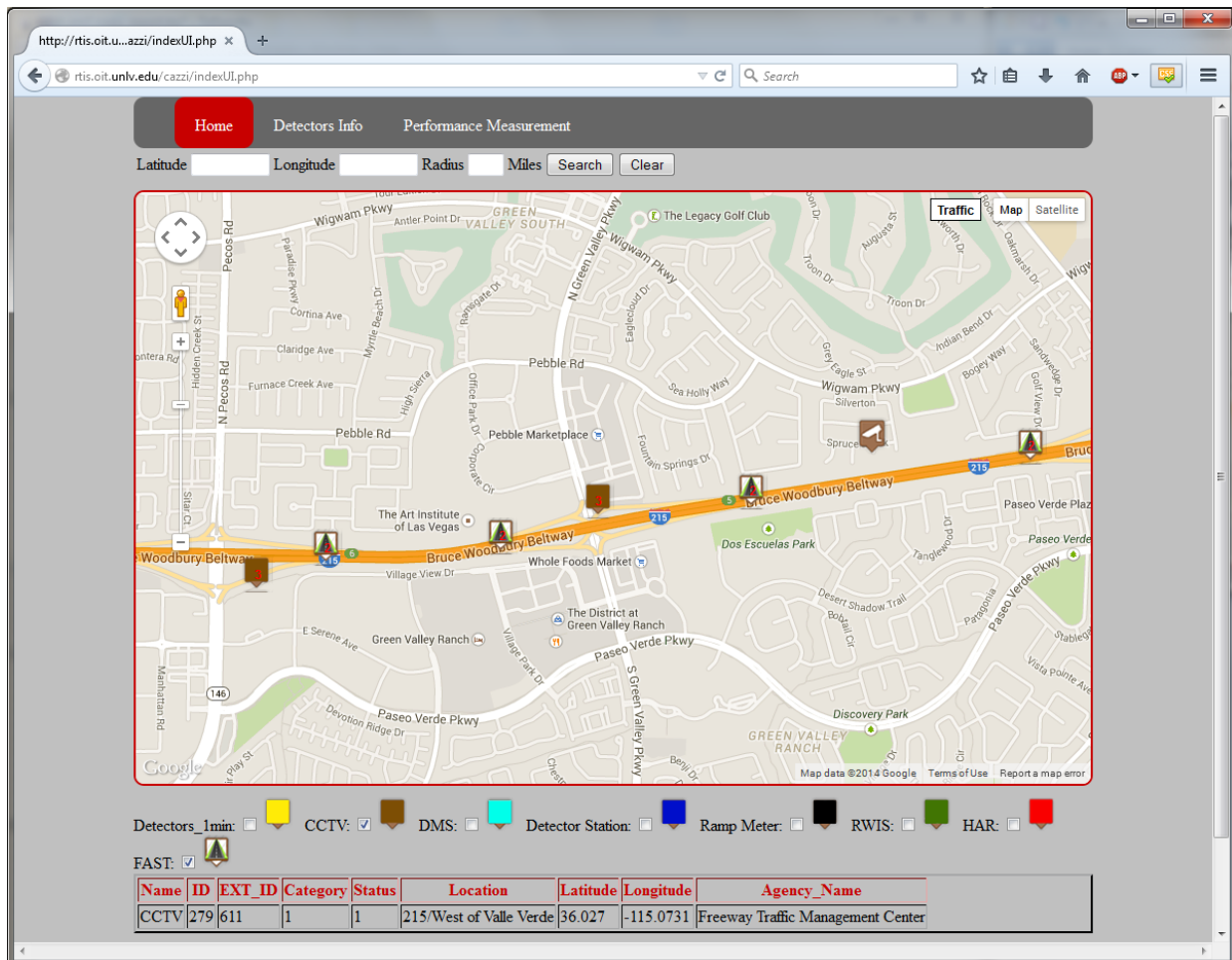


Figure 5.6: Information about individual sensors is obtained through click of a device icon.

5.4 Performance Measurement Algorithms

The most important block in the PMR system calculates Performance Measures through utilization of the database of historical and real-time measurements. The sensor systems provide the data which can be processed for advanced understanding of Las Vegas' network performance. Any of the the measures listed in Tables A.1 or A.2 can be computed given the appropriate sensors.

As an example, the AADT can be computed by extracting all the flow measurements over a year. By actively mining ITS device data, new measures can be computed and recorded into the database for better analysis. An example of next generation analysis that is possible using this paradigm is early congestion prediction through machine learning which will be outlined in the next Section.

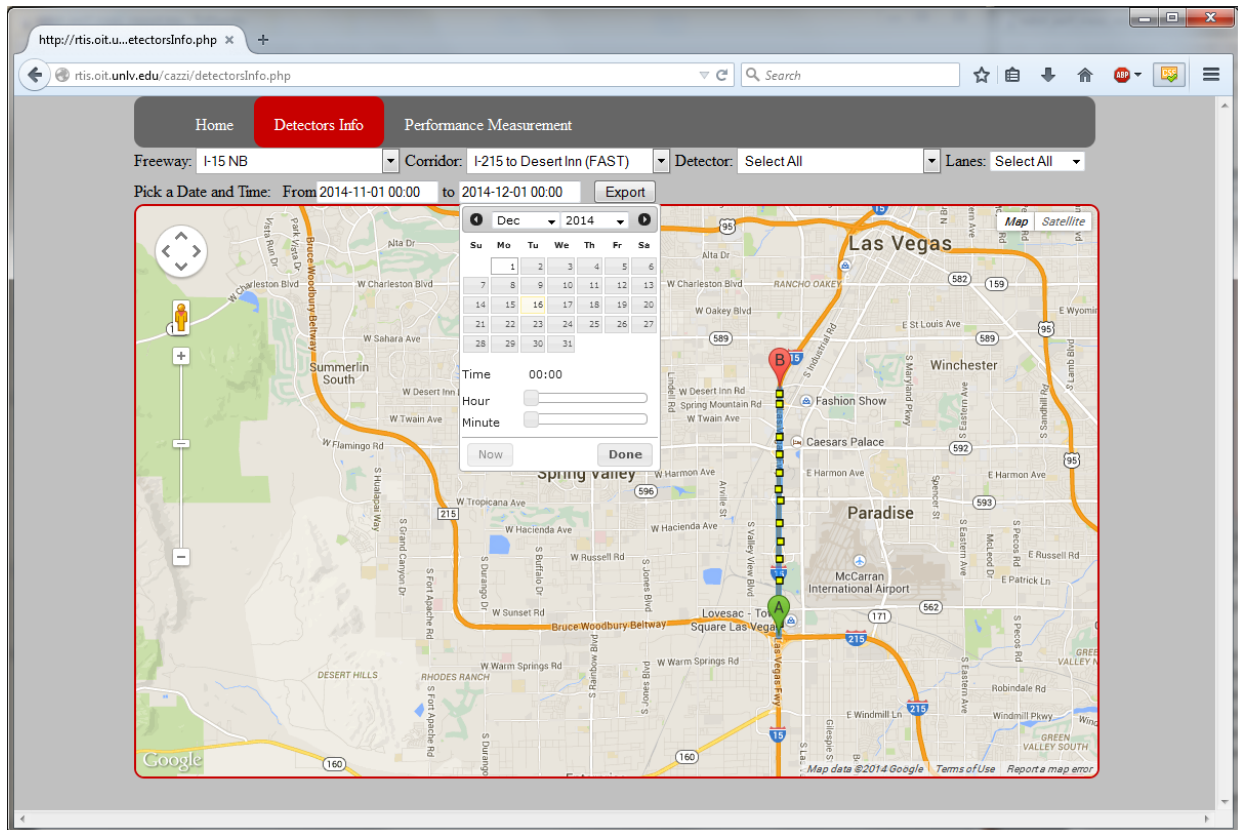


Figure 5.7: Radar detector sensor data can be downloaded from the PMR website using a simple corridor selection mechanism.

Chapter 6

Early Congestion Prediction

Growing congestion in urban transportation networks has resulted in significant economic burdens to our society. It causes waste of time, money, fuel and energy for commuters and consequently has major impacts on daily life. Based on the 2011 Congested Corridors Report presented by TTI [27], traffic congestion had a \$121 billion cost for drivers. Being aware of the status of congestion in the future can help decision makers, intelligent systems, and transportation apps improve their accuracy and enable more efficient and less stressful route choice. To achieve these goals accurate traffic status classification techniques are required.

Transportation systems are data rich with systems in place to provide real-time understanding of current traffic conditions. Data mining techniques can be utilized to determine correlations between historical observations and future roadway conditions. In particular, a congestion prediction algorithm is desired that can use historical traffic parameters of vehicle counts, occupancy, and speed on highways to understand when congestion will appear in the future.

The following Chapter highlights a early congestion prediction system that was designed for I-15 Northbound between I-215 and Desert Inn in Las Vegas. This research resulted in a paper submission to the 2015 Transportation Research Board Annual Meeting.

6.1 Previous Studies

One of the advantages of ITS is the ability reduce the impact of traffic congestion which is a common problem all over the world. ITS utilizes many detectors and sensors to collect vast quantities of data. Data mining techniques can be used to analyze this large amount of traffic flow data to extract previously unknown traffic patterns. Congestion analysis has been an active research topic during the last decade. Researchers have been interested in trying to predict the status of highways, e.g. whether there will be congestion or not.

Yu et al. [28] presented a logistic regression model to measure congestion intensity for different roadways. Hongsakham et al [29] developed a technique based on an artificial neural network (ANN) to estimate road traffic congestion levels. Their congestion estimation model had a recall of 79.43% and precision ranging from 73.53-85.19%. The studies by Pongpaibool et al [30] utilized fuzzy logic and neuro-fuzzy techniques to estimate the congestion level using data from traffic cameras with an accuracy of 88% and 75% respectively. Porikli and Li [31] used a hidden Markov modeling approach to estimate congestion status. The accuracy of their developed model is 95%. Tsai et al. [32] developed a traffic congestion classification

framework that classifies congestion into four levels. Automatic roadway detection, bidirectional roadway analysis, and virtual detector setting method are the three stages of their framework. The accuracy of their approach was 93.2%. Zhan-quan et al [33] used an SVM to identify the real-time congestion status. By using speed, volume, and occupancy as input features, they were able to obtain 94% precision. Wang et al [34] combined clustering and a decision tree classification technique for real-time congestion status with 99.3% accuracy. However, they only classified the current traffic state and did not give predictions.

A wide variety of congestion classification and prediction schemes have been attempted in literature but there is little comparison between techniques. Without common datasets, the performance from different research cannot not be fairly compared to determine which data mining technique performs best at congestion prediction. Moreover, these works do not study how far into the future congestion can be accurately predicted (prediction horizon).

6.2 Methodology

Historical data from the PMR system was utilized along with data mining techniques to predict the congestion status of a highway some minutes into the future. Different data mining techniques were compared to determine the most effective classification scheme for various amounts of historical data and prediction horizons. Evaluation was performed using one minute traffic data from I-15 Northbound from I-215 to Desert Inn in Las Vegas, Nevada.

6.2.1 Data Preparation

The flow, occupancy, and speed data was collected from the Radar sensors on I-15 Northbound between I-215 and Desert Inn. A training dataset was formed from the 1 minute historical measurements and a label for the congestion state (congested or non-congested) of a section of the highway determined by the travel speed rate (TSR) [35]

$$TSR = \frac{|free_flow_speed - average_speed|}{free_flow_speed}. \quad (6.1)$$

The TSR is the rate of reduction in speed from free flow speed due to congestion. In the TSR index calculation, the posted speed limit (65 mph) was utilized for the *free_flow_speed*. The highway is considered congested during a particular minute interval based on the following TSR threshold [32]

$$congestion = TSR > 0.5. \quad (6.2)$$

To classify the future traffic status, historical measurement data was paired with a future congestion state in order to find a relationship between observed traffic patterns and a future traffic state. A training example is composed of a label $y(t)$ and feature vector $x(t)$ for each time t in the training data set. The label is given by the TSR as $y(t) = TSR(t)$. The feature vector is

$$x_m^f(t) = [s(t - f - m + 1), c(t - f - m + 1), o(t - f - m + 1), \dots, s(t - f), c(t - f), o(t - f)], \quad (6.3)$$

Table 6.1: Congestion Classifier Algorithms

Name	Type	Description
KNN	Baseline	Simple prototype matching with linear search and no “training” required.
PART	Rule-Based	Partial tree building algorithm that is a combination of C4.5 decision tree and RIPPER algorithm.
J48	Rule-Based	Greedy top-down tree building algorithm that uses entropy-based information gain to select individual feature measures for branching.
SVM	Non-Linear	Non-linear discriminant learned in high dimensional feature spaces using kernel methods for two-class classification.
ANN	Non-linear	Non-linear output activation modeled after human neurological connections between input nodes, hidden nodes, and output node.

where $s(t - f - m + 1)$, $c(t - f - m + 1)$, and $o(t - f - m + 1)$ are the speed, count, and the occupancy respectively for a one minute sample $f + m - 1$ minutes before time t . The parameter m specifies how many minutes of historical data is used (up to five minutes) and f indicates the number of minutes into the future to predict.

Using a training data set of thousands of pairs $\{y(t), x(t)\}$, a classifier can be learned to output a future congestion state. By using data before the congestion occurs with a true congestion label, patterns can be learned that indicate the relationship between current traffic parameters and upcoming congestion events.

6.2.2 Congestion Classifiers

The WEKA data mining tool developed by the University of Waikato [36] was used to train a number of different classifiers since one of the challenges in data mining is to determine which classifier best suits a particular problem. A number of popular classification algorithms were considered for comparison. The classifiers that were used consisted of straight-forward prototype matching, rule-based algorithms, and more sophisticated machine learning techniques to develop non-linear decision rules. The list of classifiers is summarized in Table 6.1 and include

- K Nearest Neighborhood (KNN) algorithm [37] – baseline classifier that requires no “training” but instead searches for the majority vote of the K closest examples in the training dataset.
- PART algorithm [38] – a decision rule algorithm that combines a C4.5 decision tree with the RIPPER divisive algorithm to build partial trees for rule generation.
- J48 algorithm [39] – greedy algorithm to generate a decision tree in a top-down recursive manner by examining individual input features based on information gain (entropy).
- Support Vector Machine (SVM) [40] – a popular machine learning algorithm that is able to generate highly non-linear decision rules for classification between two classes using kernel methods to embed data into higher dimensional space.

- Artificial Neural Network (ANN) [41] – non-linear classifier inspired by human neurological connection in the brain where nodes are activated using a sigmoid transfer function.

6.3 Comparative Results

The different classifier algorithms were compared using historical data collected over the winter season between January and March in 2014. The evaluation trained optimized classifiers for different settings of historical data m and prediction horizon f . The performance was measured by the recall and precision defined as

$$recall = \frac{TP}{TP + FN} \qquad precision = \frac{TP}{TP + FP}, \qquad (6.4)$$

where TP are the number of true positives or correctly labeled examples, FN are the false negatives or missed times of congestion, and FP are the false positives or examples that were incorrectly labeled as congested. Ideally, a strong classifier would have high recall (all congested times are recognized) with high precision (few extra times incorrectly labeled as congested).

6.3.1 J48 Classifier

As an illustrative example of classifier performance we detail the J48 algorithm. The other classifiers have similar characteristics. The final classification rule for the J48 algorithm, a decision tree using historical measurement, is presented in Fig. 6.1 after optimization and the classifier performance is presented in Fig. 6.2. The classifier performance degrades as the prediction time becomes larger because there is less correlation between older measurements and current conditions. The rows show the performance based on the amount of historical data. There seems to be a “sweet” spot at around four minutes of historical data which is unexpected. The time horizon does not seem to matter as much, since the degradation in performance is similar for all amounts of historical information, but instead having the correct amount of data to discover the temporal trends. Too little data ($m < 3$) and the trend does not seem to be visible, but too much data ($m > 6$) and the meaningful trend is polluted by stale data.

6.3.2 Congestion Classifier Comparison

The comparison of the J48, ANN, SVM, PART and KNN using a four minute historical window is presented in Figure 6.3. The J48 algorithm has better performance compared with other algorithms. The J48 is able to classify future traffic status up to 10 minutes into future with good performance while the performance of other classifiers presented here will decrease dramatically after 6 or 7 minutes. After the J48 algorithm, the machine learning techniques SVM and ANN have reasonable performance suggesting that with more data (e.g. greater than three months) could outperform the decision tree. Note that in all cases, congestion prediction benefits from the use of historical data. Prediction accuracy is poor using only the current traffic statistics or greater than 8 or 9 minutes in the past. Clearly, only

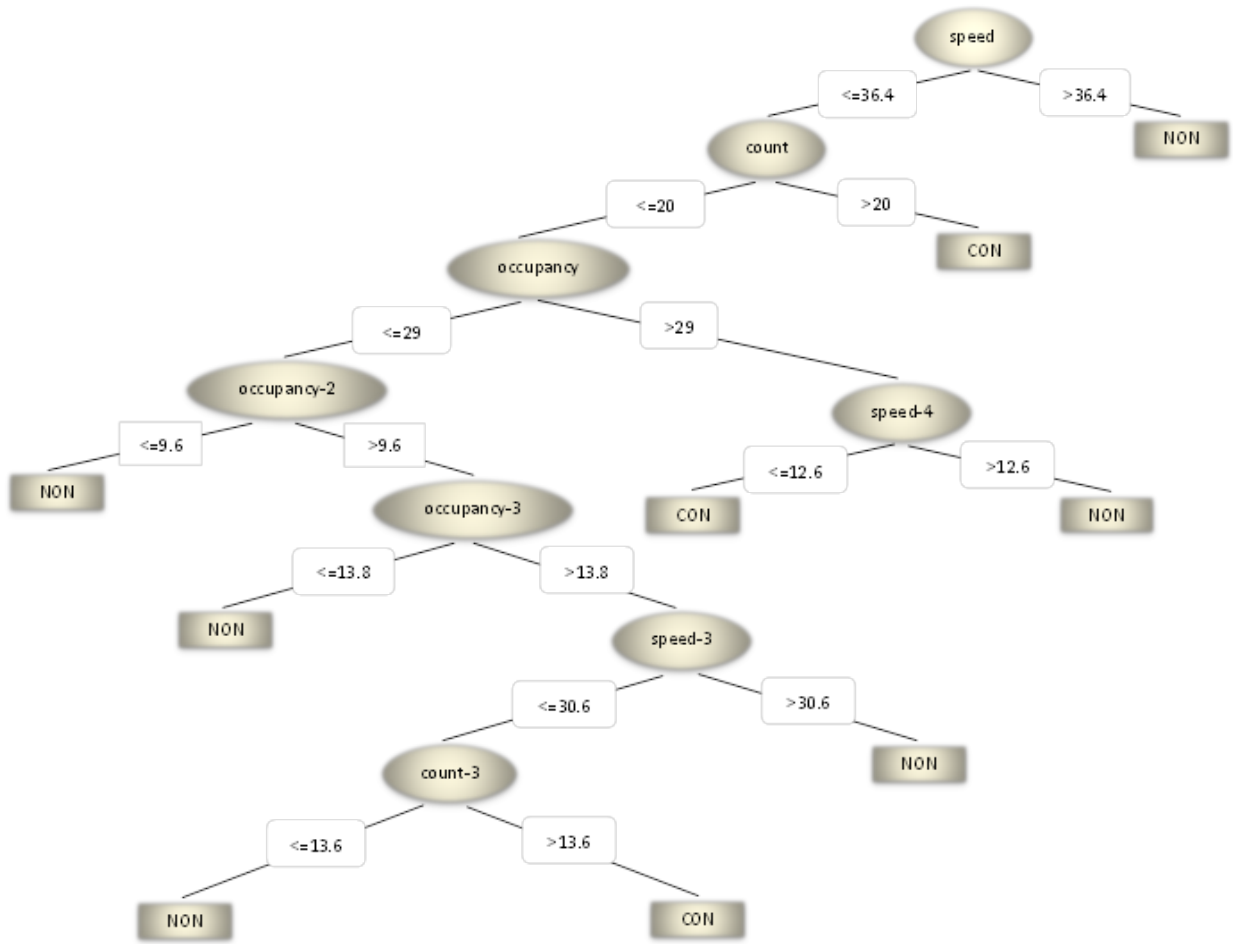


Figure 6.1: Optimized J48 decision tree for a five minute congestion prediction horizon.

considering real-time measurements is not a good indicator of future events. This indicates that temporal characteristics are being leveraged to improve performance. However, this dataset only shows correlation under 8 minutes. Future work could also consider the effects of upstream and downstream sensors for predictability.

6.4 Further Research

This research presented is able to classify the future state of traffic congestion. But there are still many issues that can be considered in congestion classification. Some of the research options to improve the predictability are as follows:

- Evaluating the performance of the classifier during different seasons to determine if adaption is necessary.
- Using ensemble classifier to build more sophisticated prediction algorithms.
- Utilizing upstream and downstream sensors to improve corridor prediction rather than just for single segments.
- Extending the model to arterials and streets which have much less data and more complicated relationships.

Recall	horizon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
historical																
1		0.67	0.64	0.57	0.48	0.42	0.37	0.32	0.24	0.21	0.15					
2		0.78	0.73	0.7	0.63	0.58	0.55	0.45	0.41	0.36	0.27					
3		0.92	0.88	0.86	0.82	0.81	0.78	0.74	0.72	0.69	0.61	0.57	0.55	0.51	0.48	0.41
4		0.96	0.96	0.96	0.95	0.91	0.87	0.85	0.82	0.82	0.78	0.67	0.64	0.62	0.6	0.52
5		0.93	0.91	0.89	0.86	0.84	0.81	0.74	0.75	0.71	0.64	0.61	0.59	0.54	0.47	0.4
6		0.86	0.85	0.81	0.77	0.74	0.71	0.68	0.62	0.57	0.51	0.48	0.43	0.41		
7		0.83	0.8	0.73	0.71	0.68	0.62	0.59	0.55	0.51	0.42	0.4				
8		0.75	0.71	0.67	0.61	0.59	0.56	0.48	0.45	0.42						
9		0.68	0.65	0.61	0.59	0.54	0.51	0.48	0.45	0.41						
Precision	horizon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
historical																
1		0.92	0.89	0.86	0.83	0.78	0.75	0.71	0.68	0.61	0.56					
2		0.93	0.92	0.89	0.86	0.84	0.82	0.78	0.75	0.7	0.66					
3		0.95	0.93	0.91	0.88	0.86	0.85	0.83	0.73	0.7	0.67	0.64	0.59	0.56	0.51	0.48
4		0.96	0.96	0.96	0.96	0.95	0.95	0.95	0.93	0.9	0.85	0.83	0.82	0.71	0.68	0.63
5		0.96	0.95	0.94	0.93	0.92	0.9	0.9	0.87	0.87	0.8	0.77	0.72	0.72	0.68	0.63
6		0.95	0.93	0.91	0.9	0.88	0.88	0.85	0.83	0.83	0.78	0.71	0.69	0.64		
7		0.93	0.88	0.85	0.82	0.78	0.75	0.71	0.64	0.56	0.51	0.49				
8		0.87	0.84	0.81	0.78	0.73	0.65	0.58	0.52	0.5						
9		0.81	0.78	0.74	0.71	0.65	0.58	0.52	0.49	0.46						

Figure 6.2: J48 recall and precision performance for various amounts of historical data and prediction horizons.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Recall	J48	0.96	0.96	0.96	0.95	0.91	0.87	0.85	0.82	0.82	0.78	0.67	0.64	0.62	0.6	0.52
	PART	0.95	0.86	0.84	0.82	0.78	0.72	0.72	0.63	0.58	0.51	0.47	0.3	0.23		
	SVM	0.95	0.87	0.87	0.82	0.79	0.73	0.69	0.65	0.6	0.56	0.39	0.34	0.3	0.17	0.13
	ANN	0.95	0.95	0.89	0.85	0.82	0.82	0.78	0.65	0.62	0.6	0.47	0.47	0.47	0.39	0.34
	KNN	0.95	0.85	0.82	0.8	0.75	0.73	0.71	0.61	0.55	0.5	0.41	0.26	0.16		
Precision	J48	0.96	0.96	0.96	0.96	0.95	0.95	0.95	0.93	0.9	0.85	0.83	0.82	0.71	0.68	0.63
	PART	0.95	0.9	0.89	0.81	0.8	0.79	0.77	0.76	0.75	0.7	0.63	0.51	0.4		
	SVM	0.95	0.9	0.87	0.85	0.81	0.79	0.77	0.75	0.75	0.73	0.71	0.71	0.7	0.6	0.54
	ANN	0.96	0.92	0.9	0.9	0.86	0.79	0.78	0.78	0.77	0.74	0.69	0.65	0.63	0.6	0.58
	KNN	0.95	0.9	0.86	0.8	0.77	0.76	0.72	0.71	0.63	0.59	0.56	0.56	0.51		

Figure 6.3: Comparison of various classification techniques for congestion prediction using a four minute historical window.

Chapter 7

Discussion and Recommendations

This project examined data collection and performance measurements for Nevada. Its focus was on the reporting requirements in the areas of construction, incidents, weather, and travel time as required by the RTSMIP. The November 2014 deadline for interstate highways was met this year leaving study of requirements for the Las Vegas metropolitan area for the second 2016 deadline. In order to meet this upcoming deadline, important ROS need to be identified for reporting.

This project identified 17 potential ROS in Las Vegas using a network screening process that accounted for usage (VMT), speed, and ability to serve as an evacuation route. Many were State Routes but unlike in some other states, these SR designations included non-highway roads which make travel time information more difficult to obtain. The report prioritizes locations for new sensor installations to provide complete ROS coverage. New side-fire microwave Radar installations are suggested for CC 215 and Summerlin Pky. which will provide travel time. Along arterial routes, a number of traffic camera locations are recommended which provide visual coverage to satisfy construction, weather, and incident monitoring and could potentially be used for travel times as well (through manual or automated video processing).

It is recommended that NDOT explore options for arterial travel time. One lower cost option is the multi-purpose use of the dense traffic camera network. This would require developing a manual “tracking” protocol along ROS at important times or by the use of automated video processing. In parallel, NDOT could initiate conversations with third party private probe data providers to fill arterial data gaps without the high cost of hardware installation and maintenance since these have been proven to meet the reporting accuracy and availability requirements. This type of data would take advantage of newer social media techniques for prompt response times and provides a scalable solution that could be applied throughout Nevada, not just Las Vegas.

The outputs from this research include:

- Reports on data collection technology, performance measures, and recommendations to meet upcoming real-time data requirements for metropolitan areas.
- Las Vegas ITS inventory with associated coverage maps and data gap identification in GIS format.
- The Performance Measurement Research System with web interface to 1-minute resolution transportation data.

- An early congestion prediction algorithm using historical traffic measurements for highways which also resulted in a submission to TRB.

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List of Abbreviations

AADT	Annual Average Daily Traffic
ANN	Artificial Neural Network
API	Application Program Interface
CCTV	Closed Circuit Television
CFR	Code of Federal Regulations
CMAQ	Congestion Mitigation and Air Quality Program
CSV	Comma Separated Value
DMS	Dynamic Message Sign
DOT	Department of Transportation
FAST	Freeway and Arterial System of Transportation
FHWA	Federal Highway Administration
FMS	Freeway Management System
FRC	Functional Road Class
GIS	Geographic Information System
HAR	Highway Advisory Radio
IRI	International Roughness Index
ITS	Intelligent Transportation System
LOS	Level of Service
MAP-21	Moving Ahead for Progress in the 21 st Century
MOE	Measure of Effectiveness
NHS	National Highway System
NDOT	Nevada Department of Transportation
PMR	Performance Measurement Research System
ROC	Road Operations Center
ROS	Routes of Significance
RTC	Regional Transportation Commission of Southern Nevada
RTSMIP	Real-Time System Management Information Program
RWIS	Road Weather Information System
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SQL	Structured Query Language
TMC	Transportation Management Center
UNLV	University of Nevada, Las Vegas
VMT	Vehicle Miles Traveled

Appendix A

Performance Measures

The following comprehensive list of performance measures, divided into area, were identified through review of literature and state-of-practice.

Table A.1: List of Performance Measures

Measure	Description (Widely used in bold)
Mobility	
Volume-to-Capacity Ratio (V/C Ratio)	The volume divided by capacity. The volume is often estimated as the 30th yearly highest volume available.
Level of Service (LOS)	A grade interval expressing how well a roadway segment is serving its traffic. It is graded from A to F, which A means free flow and F means very congested. LOS is based on a (V/C Ratio) and has long been used as the primary measure of congestion for planning purposes.
Annual Hours of Truck Delay (AHTD)	Travel time above the congestion threshold in units of vehicle-hours for Trucks on the Interstate Highway System
Travel Time Index	Ratio of average peak travel time to an off-peak (free-flow) standard.
Travel Delay	The amount of extra time which is needed for traveling due to congestion.
Percent of Congested Travel	The congested vehicle-miles of travel divided by total vehicle-miles of travel. This measure is actually a relative measure of the amount of travel affected by congestion.
Accessibility	
	Percentage of urban population within X miles of transit. The number of people accessing the system are considered to be indicators of transportation accessibility.
	Percentage of employment sites within X miles of major highways.
Cumulative Opportunity	This approach counts the number of potential opportunities that can be reached within a predetermined travel time.

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Table A.1: List of Performance Measures

Measure	Description (Widely used in bold)
Gravity or Opportunities Approach	This approach counts the mass of opportunities available to travelers considering transportation cost. The cost of moving from origin to destination affects the attractiveness of an opportunity. The further an opportunity is from the origin, in terms of time or distance or generalized cost, the lower its accessibility.
Place rank	This measure ranks each location based on the number of people commuting to the location to reach an opportunity.
Reliability	
Travel Time Window	The standard deviation of travel time or travel rate can be combined with the average for any of several measures to create a variation or reliability measure. $TTW = Avg(Travel_Time) \pm STD(Travel_Time).$
Reliability Index (RI80)	The Reliability Index is defined as the ratio of the 80th percentile travel time to the agency-determined threshold travel time.
Percent variation	The average and standard deviation values can also be combined in a ratio to produce a value that the 1998 California Transportation Plan calls percent variation. $PV = STD(Travel_Time)/Avg(Travel_Time) \times 100.$
Misery Index	This measure focuses on the length of delay of only the worst trips. The average travel rate is subtracted from the upper 10%, 15% or 20% of travel rates to get the amount of time beyond the average for some amount of the slowest trips. $MI = (Avg(longest\ 20\%) - Avg(trip))/Avg(trip).$
Variability Index	The index is a ratio of peak to off-peak variation in travel conditions. The index is calculated as a ratio of the difference in the upper and lower 95% confidence intervals between the peak period and the off-peak period.
Buffer Time	This measure the amount of extra time needed to be on time for 95% of the trips. $BT = 95\% \text{ travel time for a trip} - Avg(\text{Travel Time}).$
Buffer Time Index	Using the Buffer Time concept and the travel rate simultaneously (in minutes per mile), rather than average travel time, can address the concerns about identifying an average trip. $BTI = Avg(\text{VMT weighted section}) \times \text{Buffer time} \times 100.$

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Table A.1: List of Performance Measures

Measure	Description (Widely used in bold)
Planning Time Index	The upper end of the Buffer Time Index can also be concerned as an useful measure in some situations. The 95th percentile Travel Time Index or the travel rate (expressed in minutes per mile) is a good measure to estimate of travel time budget and is calculated as part of the Buffer Time Index process. Planning time index is relatively easy to communicate and is a good estimate of trip planning measure for trips that require on-time arrivals.
Florida Reliability Method	The Florida reliability method uses a percentage of the average travel time in the peak to estimate the limit of the acceptable additional travel time range. The sum of the additional travel time and the average time defines the expected time. $FRM = 100\% - (\% \text{ of trip with travel time greater than expected}) = 100\% - (\% \text{ of trip with travel rate greater than average for plus small (5, 10, 15, 20) \% of average.})$
On-Time Arrival	A concept similar to the Florida method uses an acceptable lateness threshold of some percentage to indicate the percentage of trip travel times that can be termed reliable. This measure is used in a variety of travel modes and services and might be particularly useful in cross-modal comparisons. $OTA = 100\% - (\% \text{ of travel time greater than } 110\% \text{ expected}) = 100\% - (\% \text{ of daily peak period travel rate average greater than } 110\% \text{ of average peak period travel rate.})$
Safety	
	Number of fatalities per 100 million vehicle-mile of travel.
	Number of accidents per 100 million vehicle-miles of travel
	Average number of fatalities per 100,000 passenger miles by considering AVO (Average Vehicle Occupancy).
Number of Traffic Fatalities	The moving average of the number of traffic fatalities within 3 or 5 years of intervals
	Number of serious injuries in traffic crashes.
Fatalities/VMT	Number of fatalities over VMT including rural, urban, and total fatalities. (VMT is the sum of distances traveled by all vehicles in certain areas for a specified period of time and is typically presented as the vehicle miles traveled per person each day or year).
	Number of unrestrained passenger vehicle occupant fatalities, all seat positions.
	Number of fatalities in crashes involving a driver or motorcycle operator with a blood alcohol concentration of .08 g/dL or higher.
	Number of speeding-related fatalities.

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Table A.1: List of Performance Measures

Measure	Description (Widely used in bold)
	Number of motorcyclist fatalities.
	Number of un-helmeted motorcyclist fatalities.
	Number of drivers 20 or younger involved in fatal crashes.
	Number of pedestrian fatalities.
	Observed seat belt use for passenger vehicles.
	Number of seat belt citations issued during grant-funded enforcement activities.
	Number of impaired-driving arrests made during grant-funded enforcement activities.
	Number of speeding citations issued during grant-funded enforcement activities.
Environment	
	Tons (in millions) of mobile source emissions from on-road vehicles.
Criteria Pollutant Emissions	Daily kilograms of on-road, mobile source criteria air pollutants (VOC, NO _x , PM, CO).
	Amount of carbon equivalent emissions or greenhouse gas emissions from transportation sources.
Total Emission per Vehicle Miles	Total amount of pollutions emitted per vehicle miles in a year.
	Amount of gallons spilled per ton-miles (waterborne and pipeline transportation systems).
	Number of people or percentage of being affected by or exposed to a significant (dangerous) decibel of noise.
Cost	
Cost of Highway Freight per Ton-Mile	This measure is related to freight, and is affected by highway conditions. It is also affected by factors unrelated to the highway system, such as truck technology, drivers' wages, and fuel costs.
Fuel Consumption per Ton-Mile	It reflects the costs associated with transport that is related to highway condition. It presents the same things as costs per ton-mile presents, but would not be affected by the prices of labor and fuel. Therefore, it is a better measure of the performance of highway-system performance in freight carriage because it reflects more costs related to highway conditions.
Total Public and Private Cost of Travel	One weakness associated with cost measures is that they do not typically account for the quality of service. This measure not only concentrates on shipping cost of goods but also costs associated with damages to goods, constructing roads, expanding and maintaining high ways. Thus this measure considers all the resource cost associated with travel.
Maintenance Costs	This measure considers the costs of constructing roads and expanding and maintaining high ways.
	Infrastructure Condition The number of bridges per 100 miles and the number of deficient bridges per 100 Miles.

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Table A.1: List of Performance Measures

Measure	Description (Widely used in bold)
	Lane-miles of high-level highway requiring rehabilitation. This measure can be a direct reflection of infrastructure condition.
	Percentage of state trunk lines which has a surface condition classified as good.
Non-Interstate NHS Pavement Condition	Percentage of .1 mile segments of non- Interstate NHS pavement mileage in good, fair and poor condition based on the following criteria: good if International Roughness Index (IRI) < 95, fair if IRI is between 95 and 170, and poor if IRI is greater than 170.
NHS Bridge Condition	Percentage of National Highway System bridges in good, fair and poor condition, weighted by deck area.
Economic Impact	
	The number of direct and indirect jobs created.
	The amount of growth in GDP associated with transportation activities.
	Revenue per ton-mile.
	The value of the freight that is moved from, to, and within the region.
Industry Productivity	
	Vehicle miles per capita.
	Passenger trips per capita.
	Revenue hours per Employee.
	Passenger trips per employee.
Traffic Data Quality	
Accuracy	The measure or degree of agreement between a data value or set of values and a source assumed to be correct.
Completeness (Availability)	The degree to which data values are present in the attributes.
Validity	The degree to which data values satisfy acceptance requirements of the validation criteria or fall within the respective domain of acceptable values.
Timeliness	The degree to which data values or a set of values are provided at the time required or specified.
Coverage	The degree to which data values in a sample accurately represent the whole of that which is to be measured.
Accessibility (Usability)	The relative ease with which data can be retrieved and manipulated by data consumers to meet their needs.

Table A.2: Congestion Performance Measures

Measure	Description (Widely used in bold)
Roadway Congestion Index	This index focuses on the physical capacity of the roadway in term of vehicles. This index measure the congestion by concentrating on daily vehicle miles traveled on roads.

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Table A.2: Congestion Performance Measures

Measure	Description (Widely used in bold)
Travel Rate Index	This index calculates the amount of additional time that is needed to make a trip because of congested conditions on the roadway. It examines how fast a trip can occur during the peak period by focusing on time rather than speed. It uses freeway and arterial road travel rates.
Travel Time Index	This index compares peak period travel and free flow travel while considering for both recurring and incident conditions. This index specify how long it to travel peak hour.
Travel Delay	Travel delay is the extra amount of time spent traveling due to congested conditions.
Annual Hours of Delay (AHD)	Travel time above a congestion threshold (defined by State DOTs and MPOs) in units of vehicle-hours of delay.
Buffer Index	The buffer index computes the extra percentage of travel time a traveler should consider when making a trip in order to be on time 95 percent of the time.
Misery Index	The misery index shows the worst 20 percent of trips that happen in congested conditions. This index examines the negative aspect of trip reliability by taking into account only the travel rate of trips that exceed the average travel rate. This index measures how bad the congestion is on the days which the congestion is the worst.
Travel Rate	Travel rate, expressed in minutes per mile, represent how quickly a vehicle travels over a certain segment of roadway. It can be used for specific segments of roadway or averaged for an entire roadway. An estimate of travel rate is usually compared to a target value to show unacceptable levels of congestion.
Delay Rate	The delay rate is the rate of time loss for vehicles operating in congested conditions on a roadway segment or during a trip. This measure can evaluate system performance and compare actual and expected performance.
Total Delay	This index is the sum of time lost on a segment of roadway associated with vehicles. This measure can show how improvements affect a transportation system, such as the effects on the entire transportation system of major improvements on one particular corridor.
Relative Delay Rate	The relative delay rate is used to compare mobility levels on roadways or between different modes of transportation. This measure compares system operations to a standard or target. It can also be utilized to compare different parts of the transportation system and reflect differences in operation between transit and roadway modes.

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Table A.2: Congestion Performance Measures

Measure	Description (Widely used in bold)
Delay Ratio	The delay ratio can be used to compare mobility levels on roadways or between different modes of transportation. This measure identifies the importance of the mobility problem in relation to actual conditions.
Congested Travel	This measure takes into account the amount and extent of congestion on roadways. Congested travel is a measure of the amount of travel that occurs during congestion in terms of vehicle-miles.
Congested Roadway	This measure takes into account the amount and extent of congestion that happens on roadways.
Speed Reduction Index	This measure represents the ratio of the decline in speeds from free flow conditions. It provides a way to compare the amount of congestion on different transportation facilities by using a continuous scale to differentiate between different levels of congestion.
Congestion Severity Index	Measure of freeway delay per million miles of travel. This measure evaluates congestion considering freeway and arterial road delay and vehicle miles traveled.
Lane-mile Duration Index	This index takes into account recurring freeway congestion. This index measures congestion by summing the product of congested lane miles and congestion duration for segments of roadway.
Level of Service	LOS differs by facility type and is presented by specifications such as vehicle density and volume to capacity ratio. Congested conditions often fall into a LOS F range, where demand exceeds capacity of the roadway. Volume to capacity ratios is compared to LOS to reach conclusions about congested conditions.
Queues	Queues, or traffic back-ups, represent the public's view of congestion. Queues are measured using aerial photography. Queues can be measured using aerial photography that often specify performance measures such as LOS and queued volume.

Appendix B

Sensor Installation Priority Tables

The following tables provide the full list of recommended camera installations for ROS coverage. The Las Vegas Valley was screened as four separate areas {North, East, South, West}. These locations were identified through network screening using various indicators of important roadways, e.g. VMT, Speed, daily flow, and FRC (Major Arterial). The rows are colored based on priority {high, medium, low} = {red, blue, green}.

Table B.1: 22 Recommended Sensors - North

	N-S Street	E-W Street	Longitude	Latitude	Priority		
					VMT	Speed	Final
1	N Decatur	Vegas Dr	-115.206131	36.188266	1	1	1
2	N Decatur	Cheyenne	-115.20772	36.217318	1	1	1
3	Simmon	Lake Mead	-115.178869	36.19739	1	2	1
4	N 5th St	Cheyenne	-115.134254	36.217764	1	1	1
5	Lamb	Cheyenne	-115.08027	36.217466	1	1	1
6	Lamb	Carey Ave	-115.079824	36.202892	1	1	1
7	N Nellis Blvd	Carey Ave	-115.062424	36.203784	1	1	1
8	N Decatur	Alexander	-115.207423	36.23204	2	2	2
9	N Decatur	Lone Mountain	-115.207423	36.247061	2	2	2
10	N MLK	Gowan	-115.161618	36.224902	2	2	2
11	N Decatur	Smoke Ranch Rd	-115.205782	36.202699		1	2
12	N Decatur	W Lake Mead	-115.205925	36.195489		1	2
13	N Decatur	W Washington Ave	-115.206068	36.18095		1	2
14	N Jones Blvd	Cheyenne	-115.225805	36.216817		1	2
15	N Jones Blvd	Vegas Dr	-115.224021	36.18862		1	2
16	N Rancho Dr	Cheyenne	-115.211885	36.217174		1	2
17	N Rancho Dr	Smoke Ranch Rd	-115.198917	36.202897		1	2
18	N MLK	Carey Ave	-115.16037	36.203254		1	2
19	Simmon	Carey Ave	-115.16037	36.203037		1	2
20	N Rancho Dr	Vegas Dr	-115.18583	36.188501		1	2
21	N Nellis Blvd	E Lake Mead Blvd	-115.062205	36.196163		1	2
22	Rampart	Vegas Dr	-115.28761	36.188658	2		3

Table B.2: 54 Recommended Sensors - East

	N-S Street	E-W Street	Longitude	Latitude	Priority		
					VMT	Speed	Final
1	Mountain Vista	E Sunset Rd	-115-071303	36-071334	1	1	1
2	Pecos, McLead	E Desert Inn	-115-109753	36-129897	1	1	1
3	Pecos, McLead	E Flamingo	-115-100901	36-115239	1	1	1
4	S Pecos	Tropicana	-115-100996	36-100011	1	1	1
5	S Pecos	E Russel Rd	-115-100996	36-0864	1	2	1
6	S Pecos	E Sunset Rd	-115-100711	36-071648	1	1	1
7	S Pecos	Warm Springs	-115-100425	36-056895	1	1	1
8	S Eastern	E Desert Inn	-115-118289	36-12979	1	1	1
9	Green valley	E Windmill	-115-0823	36-043534	1	1	1
10	Mountain Vista	E Russel Rd	-115-073377	36-08577	1	1	1
11	Nellis Blvd	E Charleston	-115-062372	36-159087	1	1	1
12	Nellis Blvd	E Sahara	-115-065346	36-144661	1	1	1
13	Nellis Blvd	E Desert Inn	-115-065643	36-12979	1	1	1
14	Nellis Blvd	E Tropicana	-115-063859	36-100344	1	1	1
15	Spencer St	Warm Springs	-115-127554	36-057629	2	2	2
16	Pecos	E Desert Inn	-115-100996	36-129802	2	2	2
17	McLead Dr	E Flamingo	-115-109848	36-115144	2	2	2
18	Pecos, McLead	E Harmon	-115-100806	36-10772	2	2	2
19	S Pecos	Hacienda	-115-101091	36-093348	2	2	2
20	S Pecos	Patrick	-115-100901	36-078976	2	2	2
21	Sandhill	E Tropicana	-115-091818	36-100344	2	2	2
22	Sandhill	E Russel Rd	-115-091074	36-085918	2	2	2
23	Sandhill	E Sunset	-115-092264	36-07179	2	2	2
24	S Maryland Pky	E Desert Inn	-115-13689	36-129939		1	2
25	Valle Verde	Warm Springs	-115-068766	36-056621	2	2	2
26	Stephanie	American Pacific Dr	-115-046756	36-041601	2	2	2
27	S Lamb Blvd	E Charleston	-115-07992	36-158789	2	2	2
28	S Lamb blvd	E Sahara	-115-083043	36-144215	2	2	2
29	S Maryland Pky	E Charleston	-115-137033	36-158921		1	2
30	S Maryland Pky	E Russel Rd	-115-136747	36-089108		1	2
31	Pacific Ave	Vanwagenen	-114-987769	36-028657		1	2
32	Green Valley	Vanwagenen	-114-970816	36-022114		1	2
33	Green Valley	Horizon	-114-976705	36-012715		1	2
34	College Dr	Horizon	-114-963261	36-01265		1	2
35	S Racetrack Rd	Newport	-114-949757	36-02723		1	2
36	S Racetrack Rd	Burkholder	-114-949757	36-034487		1	2
37	S Racetrack Rd	Warm Springs	-114-949817	36-049002		1	2
38	S Racetrack Rd	Athens Ave	-114-949698	36-071071		1	2
39	S Magic Way	Equestrian Dr	-114-940775	36-012596		1	2
40	S Magic Way	Newport	-114-940775	36-02723		1	2

Continued on next page ...

Table B.2: 54 Recommended Sensors - East

	N-S Street	E-W Street	Longitude	Latitude	Priority		
					VMT	Speed	Final
41	Apaloosa	Equestrian Dr	-114.931792	36.012537		1	2
42	Apaloosa	Wagon Wheel	-114.931495	35.998081		1	2
43	Foothills	Equestrian Dr	-114.923167	36.012596		1	2
44	Foothills	Wagon Wheel	-114.923167	35.99826		1	2
45		E Sunset Rd	-115.157793	36.071332	3		3
46		E Sunset Rd	-115.134621	36.071762	3		3
47		S Maryland	-115.136925	36.153177	3	3	3
48		E Russel Rd	-115.14097	36.088991	3		3
49	Swenson St	E Desert Inn	-115.146009	36.129834	2		3
50	Cambridge St	E Desert Inn	-115.141406	36.129775	2		3
51		E Desert Inn	-115.128312	36.130087	3	3	3
52		E Tropicana	-115.107468	36.100011	3	3	3
53	Green Valley	Heater Dr	-114.976645	36.005279		2	3
54	College Dr	Heater Dr	-114.963201	36.00522		2	3

Table B.3: 61 Recommended Sensors - West

	N-S Street	E-W Street	Longitude	Latitude	Priority		
					VMT	Speed	Final
1	S Town Center	W Desert Inn	-115.324933	36.129757	1	1	1
2	S Fort Apach Rd	W Desert Inn	-115.297033	36.129899	1	1	1
3	S Durango Dr	W Desert Inn	-115.278593	36.129304	1	1	1
4	S Durango Dr	W Flamingo	-115.279039	36.114878	1	1	1
5	S Durango Dr	W Tropicana	-115.279375	36.100071	1	1	1
6	S Buffalo Dr	W Desert Inn	-115.261004	36.129197	1	1	1
7	S Buffalo Dr	W Flamingo	-115.260976	36.114686	1	1	1
8	S Buffalo Dr	W Russel Rd	-115.260933	36.08489	1	1	1
9	S Rainbow Blvd	W Tropicana	-115.243071	36.099836	1	1	1
10	S Jones Blvd	W Desert Inn	-115.224949	36.129138	1	1	1
11	S Jones Blvd	W Flamingo	-115.224864	36.1145	1	1	1
12	S Decatur Blvd	W Desert Inn	-115.208088	36.130048	1	1	1
13	S Decatur Blvd	W Tropicana	-115.208016	36.100923	1	1	1
14	S Valley View Blvd	W Charleston	-115.19257	36.15908	1	1	1
15	S Valley View Blvd	W Tropicana	-115.189774	36.100843	1	1	1
16	S Valley View Blvd	W Russel Rd	-115.190012	36.086269	1	2	1
17	S Buffalo Dr	Alta Dr	-115.259897	36.166626	2	2	2
18	S Buffalo Dr	W Twain Ave	-115.262978	36.121976	2	2	2
19	S Rainbow Blvd	Edna Ave	-115.242904	36.134957	2	2	2
20	S Rainbow Blvd	W Hacienda	-115.243005	36.092376	2	2	2
21	S Rainbow Blvd	Patrick	-115.242619	36.077862	2	2	2
22	S Torrey Pines Dr	W Desert Inn	-115.234098	36.129287	2	2	2
23	S Torrey Pines Dr	W Flamingo	-115.233884	36.114478	2	2	2
24	S Torrey Pines Dr	W Tropicana	-115.234098	36.09988	2	2	2
25	S Jones Blvd	W Twain Ave	-115.224921	36.121781	2	2	2
26	S Jones Blvd	W Harmon Ave	-115.22494	36.107162	2	2	2
27	S Jones Blvd	W Tropicana	-115.225035	36.09989	1	1	2
28	S Jones Blvd	W Hacienda	-115.225073	36.092676	2	2	2
29	Lindel Rd	W Sahara	-115.216703	36.144365	2	2	2
30	Lindel Rd	W Desert Inn	-115.216494	36.129593	2	2	2
31	Lindel Rd	W Flamingo	-115.216456	36.114993	2	2	2
32	Lindel Rd	W Tropicana	-115.216494	36.100373	2	2	2
33	Lindel Rd	W Russel Rd	-115.216627	36.085887	2	2	2
34	S Decatur Blvd	W Twain Ave	-115.208183	36.122553	2	2	2
35	S Decatur Blvd	W Harmon Ave	-115.20804	36.108157	2	2	2
36	S Decatur Blvd	W Hacienda	-115.207945	36.093666	2	2	2
37	Arville st	W Desert Inn	-115.199114	36.129991	2	2	2
38	Arville st	W Flamingo	-115.199292	36.115298	2	2	2
39	Arville st	W Russel Rd	-115.199233	36.086388	2	2	2
40	S El Capitan	W Desert Inn	-115.288023	36.129579	2	2	2

Continued on next page ...

Table B.3: 61 Recommended Sensors - West

	N-S Street	E-W Street	Longitude	Latitude	Priority		
					VMT	Speed	Final
41	S Cimarron Rd	W Desert Inn	-115.269748	36.129364	2	2	2
42	S Cimarron Rd	W Flamingo	-115.269963	36.114659	2	2	2
43	Tenaya	W Tropicana	-115.252113	36.099739	2	2	2
44	Tenaya	W Flamingo	-115.251716	36.114697	2	2	2
45	Tenaya	W Desert Inn	-115.251866	36.129019	2	2	2
46	S Town Center	W Sahara	-115.326348	36.144181		1	2
47	S Hualapai	W Desert Inn	-115.314739	36.129858		1	2
48	S Durango	W Tropicana	-115.279232	36.100064		1	2
49	S Buffalo	W Tropicana	-115.261043	36.099788		1	2
50	S Jones Blvd	W Russel Rd	-115.225265	36.085449		1	2
51		W Sahara	-115.287664	36.144324	3		3
52	S Buffalo Dr	Edna Ave	-115.261023	36.136488	2		3
53	S Torrey Pines Dr	W Russel Rd	-115.234092	36.085223	2		3
54	S Jones Blvd	Edna Ave	-115.225182	36.136757	2		3
55	Arville st	W Tropicana	-115.199173	36.100902	2		3
56	Apple Dr	W Charleston	-115.303067	36.158988	2		3
57	S Fort Apach Rd	Mariner Cove Dr	-115.297382	36.137566	2		3
58		W Tropicana	-115.267907	36.099769	3	2	3
59	S Rainbow Blvd	Alta Dr	-115.244253	36.166483		2	3
60	Lindel Rd	W Sunset Rd	-115.215997	36.071388		2	3
61	S Buffalo Dr	W Oakey Blvd	-115.26155	36.15131		2	3

Table B.4: 7 Recommended Sensors - South

	N-S Street	E-W Street	Longitude	Latitude	Priority		
					VMT	Speed	Final
1	S Buffalo	Blue Diamond	-115.26128	36.02034	1	1	1
2	S Durango	Blue Diamond	-115.279364	36.020111	1	1	1
3	S Decatur	Warm Springs	-115.208218	36.057469	2	2	2
4	S Durango	Warm Springs	-115.279126	36.055327	2	2	2
5	Spencer	St Rose	-115.126207	35.998909	2		3
6	S Las Vegas	Cactus Ave	-115.172526	35.999172	2		3
7	S Bermuda Rd	St Rose	-115.154895	35.978062		2	3

Appendix C

PRM SQL Database Creation Script

The following SQL code generates the database tables. Care should be taken when using the script because the code was designed during the creation and testing phase. The script will drop all existing databases during creating therefore cannot be used to modify an existing database without modification or data will be lost. Each row in a lane table as a unique index as well as two foreign indices to point to the detector id and the timestamp for efficient search and retrieval.

```
1 SET @OLD_UNIQUE_CHECKS=@@UNIQUE_CHECKS, UNIQUE_CHECKS=0;
2 SET @OLD_FOREIGN_KEY_CHECKS=@@FOREIGN_KEY_CHECKS, FOREIGN_KEY_CHECKS=0;
3 SET @OLD_SQL_MODE=@@SQL_MODE, SQL_MODE='TRADITIONAL,ALLOW_INVALID_DATES';
4
5 --- Table 'fast_realtime3'.'detectors'
6
7 DROP TABLE IF EXISTS 'fast_realtime3'.'detectors' ;
8 CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'detectors' (
9   'detector_index' INT NOT NULL AUTO_INCREMENT,
10  'detector_id' VARCHAR(45) NULL,
11  PRIMARY KEY ('detector_index'),
12  UNIQUE INDEX 'detector_id_UNIQUE' ('detector_id' ASC),
13  UNIQUE INDEX 'dectector_index_UNIQUE' ('detector_index' ASC))
14 ENGINE = InnoDB;
15
16 --- Table 'fast_realtime3'.'dates'
17
18 DROP TABLE IF EXISTS 'fast_realtime3'.'dates' ;
19 CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'dates' (
20   'date_index' INT NOT NULL AUTO_INCREMENT,
21   'date_time' DATETIME NULL,
22   PRIMARY KEY ('date_index'),
23   UNIQUE INDEX 'date_time_UNIQUE' ('date_time' ASC),
24   UNIQUE INDEX 'date_index_UNIQUE' ('date_index' ASC))
25 ENGINE = InnoDB;
26
27
28
29 --- Table 'fast_realtime3'.'lane1'
30
31 DROP TABLE IF EXISTS 'fast_realtime3'.'lane1' ;
32 CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'lane1' (
```

```

33 'index' INT NOT NULL AUTO_INCREMENT,
34 'lane1_index_detector' INT NOT NULL,
35 'lane1_index_date' INT NOT NULL,
36 'lane_vehicle_count' INT NULL,
37 'lane_vehicle_count1' INT NULL,
38 'lane_vehicle_count2' INT NULL,
39 'lane_vehicle_count3' INT NULL,
40 'lane_vehicle_count4' INT NULL,
41 'lane_vehicle_count5' INT NULL,
42 'lane_vehicle_count6' INT NULL,
43 'occupancy' INT NULL,
44 'lane_vehicle_speed' INT NULL,
45 PRIMARY KEY ('index', 'lane1_index_detector', 'lane1_index_date'),
46 UNIQUE INDEX 'index_UNIQUE' ('index' ASC),
47 INDEX 'fk_lane1_detector_idx' ('lane1_index_detector' ASC),
48 INDEX 'fk_lane1_date_idx' ('lane1_index_date' ASC),
49 CONSTRAINT 'fk_lane1_detector'
50 FOREIGN KEY ('lane1_index_detector')
51 REFERENCES 'fast_realtime3'.'detectors' ('detector_index')
52 ON DELETE CASCADE
53 ON UPDATE CASCADE,
54 CONSTRAINT 'fk_lane1_date'
55 FOREIGN KEY ('lane1_index_date')
56 REFERENCES 'fast_realtime3'.'dates' ('date_index')
57 ON DELETE CASCADE
58 ON UPDATE CASCADE)
59 ENGINE = InnoDB;

```

```

61 -- Table 'fast_realtime3'.'lane2'

```

```

63 DROP TABLE IF EXISTS 'fast_realtime3'.'lane2';
64 CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'lane2' (
65 'index' INT NOT NULL AUTO_INCREMENT,
66 'lane2_index_detector' INT NOT NULL COMMENT ' ',
67 'lane2_index_date' INT NOT NULL,
68 'lane_vehicle_count' INT NULL,
69 'lane_vehicle_count1' INT NULL,
70 'lane_vehicle_count2' INT NULL,
71 'lane_vehicle_count3' INT NULL,
72 'lane_vehicle_count4' INT NULL,
73 'lane_vehicle_count5' INT NULL,
74 'lane_vehicle_count6' INT NULL,
75 'occupancy' INT NULL,
76 'lane_vehicle_speed' INT NULL,
77 PRIMARY KEY ('index', 'lane2_index_detector', 'lane2_index_date'),
78 UNIQUE INDEX 'index_UNIQUE' ('index' ASC),
79 INDEX 'fk_lane2_date_idx' ('lane2_index_date' ASC),
80 INDEX 'fk_lane2_detector_idx' ('lane2_index_detector' ASC),
81 CONSTRAINT 'fk_lane2_detector'
82 FOREIGN KEY ('lane2_index_detector')
83 REFERENCES 'fast_realtime3'.'detectors' ('detector_index')
84 ON DELETE CASCADE
85 ON UPDATE CASCADE,
86 CONSTRAINT 'fk_lane2_date'
87 FOREIGN KEY ('lane2_index_date')

```

```

      REFERENCES 'fast_realtime3'.'dates' ('date_index')
89     ON DELETE CASCADE
      ON UPDATE CASCADE)
91 ENGINE = InnoDB;
-----
93 -- Table 'fast_realtime3'.'lane3'
-----
95 DROP TABLE IF EXISTS 'fast_realtime3'.'lane3' ;
CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'lane3' (
97     'index' INT NOT NULL AUTO_INCREMENT,
      'lane3_index_detector' INT NOT NULL,
99     'lane3_index_date' INT NOT NULL,
      'lane_vehicle_count' INT NULL,
101     'lane_vehicle_count1' INT NULL,
      'lane_vehicle_count2' INT NULL,
103     'lane_vehicle_count3' INT NULL,
      'lane_vehicle_count4' INT NULL,
105     'lane_vehicle_count5' INT NULL,
      'lane_vehicle_count6' INT NULL,
107     'occupancy' INT NULL,
      'lane_vehicle_speed' INT NULL,
109     PRIMARY KEY ('index', 'lane3_index_detector', 'lane3_index_date'),
      UNIQUE INDEX 'index_UNIQUE' ('index' ASC),
111     INDEX 'fk_lane3_detector_idx' ('lane3_index_detector' ASC),
      INDEX 'fk_lane3_date_idx' ('lane3_index_date' ASC),
113     CONSTRAINT 'fk_lane3_detector'
      FOREIGN KEY ('lane3_index_detector')
115     REFERENCES 'fast_realtime3'.'detectors' ('detector_index')
      ON DELETE CASCADE
117     ON UPDATE CASCADE,
      CONSTRAINT 'fk_lane3_date'
119     FOREIGN KEY ('lane3_index_date')
      REFERENCES 'fast_realtime3'.'dates' ('date_index')
121     ON DELETE CASCADE
      ON UPDATE CASCADE)
123 ENGINE = InnoDB;
-----
125 -- Table 'fast_realtime3'.'lane4'
-----
127 DROP TABLE IF EXISTS 'fast_realtime3'.'lane4' ;
CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'lane4' (
129     'index' INT NOT NULL AUTO_INCREMENT,
      'lane4_index_detector' INT NOT NULL,
131     'lane4_index_date' INT NOT NULL,
      'lane_vehicle_count' INT NULL,
133     'lane_vehicle_count1' INT NULL,
      'lane_vehicle_count2' INT NULL,
135     'lane_vehicle_count3' INT NULL,
      'lane_vehicle_count4' INT NULL,
137     'lane_vehicle_count5' INT NULL,
      'lane_vehicle_count6' INT NULL,
139     'occupancy' INT NULL,
      'lane_vehicle_speed' INT NULL,
141     PRIMARY KEY ('index', 'lane4_index_detector', 'lane4_index_date'),
      UNIQUE INDEX 'index_UNIQUE' ('index' ASC),

```

```

143 INDEX 'fk_lane4_detector_idx' ('lane4_index_detector' ASC),
144 INDEX 'fk_lane4_date_idx' ('lane4_index_date' ASC),
145 CONSTRAINT 'fk_lane4_detector'
146     FOREIGN KEY ('lane4_index_detector')
147     REFERENCES 'fast_realtime3'.'detectors' ('detector_index')
148     ON DELETE CASCADE
149     ON UPDATE CASCADE,
150 CONSTRAINT 'fk_lane4_date'
151     FOREIGN KEY ('lane4_index_date')
152     REFERENCES 'fast_realtime3'.'dates' ('date_index')
153     ON DELETE CASCADE
154     ON UPDATE CASCADE)
155 ENGINE = InnoDB;

```

```

157 -- Table 'fast_realtime3'.'lane5'

```

```

159 DROP TABLE IF EXISTS 'fast_realtime3'.'lane5' ;
160 CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'lane5' (
161     'index' INT NOT NULL AUTO_INCREMENT,
162     'lane5_index_detector' INT NOT NULL,
163     'lane5_index_date' INT NOT NULL,
164     'lane_vehicle_count' INT NULL,
165     'lane_vehicle_count1' INT NULL,
166     'lane_vehicle_count2' INT NULL,
167     'lane_vehicle_count3' INT NULL,
168     'lane_vehicle_count4' INT NULL,
169     'lane_vehicle_count5' INT NULL,
170     'lane_vehicle_count6' INT NULL,
171     'occupancy' INT NULL,
172     'lane_vehicle_speed' INT NULL,
173     PRIMARY KEY ('index', 'lane5_index_detector', 'lane5_index_date'),
174     INDEX 'fk_lane5_detector_idx' ('lane5_index_detector' ASC),
175     INDEX 'fk_lane5_date_idx' ('lane5_index_date' ASC),
176     UNIQUE INDEX 'index_UNIQUE' ('index' ASC),
177     CONSTRAINT 'fk_lane5_detector'
178         FOREIGN KEY ('lane5_index_detector')
179         REFERENCES 'fast_realtime3'.'detectors' ('detector_index')
180         ON DELETE CASCADE
181         ON UPDATE CASCADE,
182     CONSTRAINT 'fk_lane5_date'
183         FOREIGN KEY ('lane5_index_date')
184         REFERENCES 'fast_realtime3'.'dates' ('date_index')
185         ON DELETE CASCADE
186         ON UPDATE CASCADE)
187 ENGINE = InnoDB;

```

```

189 -- Table 'fast_realtime3'.'lane6'

```

```

191 DROP TABLE IF EXISTS 'fast_realtime3'.'lane6' ;
192 CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'lane6' (
193     'index' INT NOT NULL AUTO_INCREMENT,
194     'lane6_index_detector' INT NOT NULL,
195     'lane6_index_date' INT NOT NULL,
196     'lane_vehicle_count' INT NULL,
197     'lane_vehicle_count1' INT NULL,

```

```

199 'lane_vehicle_count2' INT NULL,
200 'lane_vehicle_count3' INT NULL,
201 'lane_vehicle_count4' INT NULL,
202 'lane_vehicle_count5' INT NULL,
203 'lane_vehicle_count6' INT NULL,
204 'occupancy' INT NULL,
205 'lane_vehicle_speed' INT NULL,
206 PRIMARY KEY ('index', 'lane6_index_detector', 'lane6_index_date'),
207 UNIQUE INDEX 'index_UNIQUE' ('index' ASC),
208 INDEX 'fk_lane6_date_idx' ('lane6_index_date' ASC),
209 INDEX 'fk_lane6_detector_idx' ('lane6_index_detector' ASC, 'lane6_index_date'
210 'ASC'),
211 CONSTRAINT 'fk_lane6_detector'
212 FOREIGN KEY ('lane6_index_detector')
213 REFERENCES 'fast_realtime3'.'detectors' ('detector_index')
214 ON DELETE CASCADE
215 ON UPDATE CASCADE,
216 CONSTRAINT 'fk_lane6_date'
217 FOREIGN KEY ('lane6_index_date')
218 REFERENCES 'fast_realtime3'.'dates' ('date_index')
219 ON DELETE CASCADE
220 ON UPDATE CASCADE)
221 ENGINE = InnoDB;

```

```

222 -- Table 'fast_realtime3'.'lane7'

```

```

223 DROP TABLE IF EXISTS 'fast_realtime3'.'lane7' ;
224 CREATE TABLE IF NOT EXISTS 'fast_realtime3'.'lane7' (
225 'index' INT NOT NULL AUTO_INCREMENT,
226 'lane7_index_detector' INT NOT NULL,
227 'lane7_index_date' INT NOT NULL,
228 'lane_vehicle_count' INT NULL,
229 'lane_vehicle_count1' INT NULL,
230 'lane_vehicle_count2' INT NULL,
231 'lane_vehicle_count3' INT NULL,
232 'lane_vehicle_count4' INT NULL,
233 'lane_vehicle_count5' INT NULL,
234 'lane_vehicle_count6' INT NULL,
235 'occupancy' INT NULL,
236 'lane_vehicle_speed' INT NULL,
237 PRIMARY KEY ('index', 'lane7_index_detector', 'lane7_index_date'),
238 UNIQUE INDEX 'index_UNIQUE' ('index' ASC),
239 INDEX 'fk_lane7_date_idx' ('lane7_index_date' ASC),
240 INDEX 'fk_lane7_detector_idx' ('lane7_index_detector' ASC),
241 CONSTRAINT 'fk_lane7_detector'
242 FOREIGN KEY ('lane7_index_detector')
243 REFERENCES 'fast_realtime3'.'detectors' ('detector_index')
244 ON DELETE CASCADE
245 ON UPDATE CASCADE,
246 CONSTRAINT 'fk_lane7_date'
247 FOREIGN KEY ('lane7_index_date')
248 REFERENCES 'fast_realtime3'.'dates' ('date_index')
249 ON DELETE CASCADE
250 ON UPDATE CASCADE)
251 ENGINE = InnoDB;

```



```
253 SET SQL_MODE=@OLD_SQL_MODE;  
SET FOREIGN_KEY_CHECKS=@OLD_FOREIGN_KEY_CHECKS;  
SET UNIQUE_CHECKS=@OLD_UNIQUE_CHECKS;
```

Appendix D

FMS Data Download and PMR Storage Script

A Python script was written to obtain sensor data from the field. The script is automatically run each minute through a cron job on a Linux server. The script connects with the FAST FTP server to obtain the FMS XML output `metadata.xml` and `realtime.xml`. The realtime data is parsed based off of XML tags and organized for insertion into the PMR database.

Code for the script is provided below:

```
1 # mysql connector lib and dictionary
2 import mysql.connector
3 from collections import OrderedDict
4 #library for the extraction from the ftp server
5 import ftplib
6 import urllib
7 #timer lib
8 import time
9 import math
10
11
12 #library to convert xml file to other format
13 from xmlutils.xml2json import xml2json
14 from xmlutils.xml2sql import xml2sql
15
16 import os
17 import re
18
19 def realtime_data_collector():
20     ## Obtaining Realtime file from FTP sever ##
21
22     # creating a new directory and change directory
23     if not os.path.exists("realtime_files"):
24         os.makedirs("realtime_files")
25
26     a=os.getcwd()
27     print(a)
28     os.chdir(a+"/realtime_files")
29     b=os.getcwd()
30     print(b)
```

```

32 decision=True
33 ret_realtime=[]
34 ret_metadata=[]
35 rFile='realtime.xml'
36
37 # connect to TRC server
38 print("connecting to TRC server...")
39 ftp=ftplib.FTP('www.nvfast.org','anonymous','anonymous@sUNET.se')
40 ftp.cwd("/FMSXML/")
41
42 while(decision):
43     files=ftp.dir()
44
45     ftp.sendcmd("TYPE i")
46     rSize = ftp.size(rFile)
47     ftp.dir('realtime.xml',ret_realtime.append)
48
49     str_realtime=''.join(ret_realtime)
50     realtime_words=str_realtime.split()
51
52 #parse file for data collection info
53 fileSizeRT=realtime_words[4]
54 monthRT=realtime_words[5]
55 dayRT=realtime_words[6]
56 timeRT=realtime_words[7]
57 hourRT=timeRT[0:2]
58 minuteRT=timeRT[3:5]
59
60 #timestamp file
61 fileName_realtime= monthRT+dayRT+'_'+hourRT+minuteRT+'_r.xml'
62 fileName_realtime2=monthRT+'_'+dayRT+'_'+hourRT+'_'+minuteRT
63
64 copyRealTime=open(fileName_realtime,'wb')
65
66 ftp.retrbinary('RETR realtime.xml', copyRealTime.write)
67 copiedSize=copyRealTime.tell()
68
69 copyRealTime.close()
70 if copiedSize==rSize:
71     print("Transfer completed", rSize, copiedSize)
72     decision=False
73 else:
74     print("Bad Transfer",rSize, copiedSize)
75     os.remove(fileName_realtime)
76     del ret_realtime[:]
77
78 ftp.close()
79
80 realtimedataSQL=fileName_realtime2+"_r.sql"
81 timeSQL=fileName_realtime2+"_r_stamp.sql"
82
83 #convert xml to ~sql-like format for easier parsing
84 converter_data = xml2sql(fileName_realtime, realtimedataSQL, encoding="utf-8")
85 ignore1=["lane-data","lane-data-item","detector-lane-number","detector-

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```

status", "lane-status"]
num=converter_data.convert(tag="detector-report", table="Realime.Data",
ignore=ignore1)
86
converter_time_stamp=xml2sql(fileName_realtime, timeSQL, encoding="utf-8")
88 converter_time_stamp.convert(tag="detection-time-stamp", table="
Realime.Data_time_stamp")
SQLcomplete=[realtimedataSQL, timeSQL]
90
SQLcomplete=[realtimedataSQL, timeSQL]
92
## comment out this line if you don't want to keep xml file
os.remove(fileName_realtime)
94
return SQLcomplete
96
98
def parsingDetectors(names):
100 ##10.18.17.93
##131.216.87.107
102 cnx=mysql.connector.connect(user='jmc', password='jmc', host='10.18.17.93',
database='fast_realtime3')
print('connection is established to mysql database: fast_realtime3')
104 cursor_mysql=cnx.cursor()
cnx.autocommit=False
106
insertCommandDetectors="INSERT IGNORE INTO 'detectors' ('detector_id'
VALUES"
108
insertCommandDate="INSERT IGNORE INTO 'dates' ('date_time') VALUES"
110
insertCommandLane1="INSERT INTO 'lane1' ('lane1_index_detector', '
lane1_index_date', 'lane_vehicle_count', 'lane_vehicle_count1', '
lane_vehicle_count2', 'lane_vehicle_count3', 'lane_vehicle_count4', '
lane_vehicle_count5', 'lane_vehicle_count6', 'occupancy', '
lane_vehicle_speed') VALUES"
112 insertCommandLane2="INSERT INTO 'lane2' ('lane2_index_detector', '
lane2_index_date', 'lane_vehicle_count', 'lane_vehicle_count1', '
lane_vehicle_count2', 'lane_vehicle_count3', 'lane_vehicle_count4', '
lane_vehicle_count5', 'lane_vehicle_count6', 'occupancy', '
lane_vehicle_speed') VALUES"
insertCommandLane3="INSERT INTO 'lane3' ('lane3_index_detector', '
lane3_index_date', 'lane_vehicle_count', 'lane_vehicle_count1', '
lane_vehicle_count2', 'lane_vehicle_count3', 'lane_vehicle_count4', '
lane_vehicle_count5', 'lane_vehicle_count6', 'occupancy', '
lane_vehicle_speed') VALUES"
114 insertCommandLane4="INSERT INTO 'lane4' ('lane4_index_detector', '
lane4_index_date', 'lane_vehicle_count', 'lane_vehicle_count1', '
lane_vehicle_count2', 'lane_vehicle_count3', 'lane_vehicle_count4', '
lane_vehicle_count5', 'lane_vehicle_count6', 'occupancy', '
lane_vehicle_speed') VALUES"
insertCommandLane5="INSERT INTO 'lane5' ('lane5_index_detector', '
lane5_index_date', 'lane_vehicle_count', 'lane_vehicle_count1', '
lane_vehicle_count2', 'lane_vehicle_count3', 'lane_vehicle_count4', '
lane_vehicle_count5', 'lane_vehicle_count6', 'occupancy', '

```

```

lane_vehicle_speed ') VALUES"
116 insertCommandLane6="INSERT INTO 'lane6'('lane6_index_detector ', '
lane6_index_date ', 'lane_vehicle_count ', 'lane_vehicle_count1 ', '
lane_vehicle_count2 ', 'lane_vehicle_count3 ', 'lane_vehicle_count4 ', '
lane_vehicle_count5 ', 'lane_vehicle_count6 ', 'occupancy ', '
lane_vehicle_speed ') VALUES"
insertCommandLane7="INSERT INTO 'lane7'('lane7_index_detector ', '
lane7_index_date ', 'lane_vehicle_count ', 'lane_vehicle_count1 ', '
lane_vehicle_count2 ', 'lane_vehicle_count3 ', 'lane_vehicle_count4 ', '
lane_vehicle_count5 ', 'lane_vehicle_count6 ', 'occupancy ', '
lane_vehicle_speed ') VALUES"
118
lines =[]
120 replacedLine2=[]
detectorsInfo =[]
122 dateInfo=[]
detectorsDate=[]
124 detectorTime=[]
counter2=0
126 a=[]
counter=0
128
print("SQL file name: "+names[0])
130 print("SQL file name: "+names[1])
132
fb_data2=open(names[1], 'r')
for line2 in fb_data2:
134     replacedLine2=line2.replace("'", "'")
    dateInfo.append(replacedLine2)
136 fb_data2.close()
dates=dateInfo
138
for i in range(2, len(dates)-1):
140     datetime=dates[i]
    checkdate=datetime
142     checkdate=checkdate[2:10]+checkdate[14:-4]
    cursor_mysql.execute("SELECT LAST_INSERT_ID( MAX( date-time ) ) FROM
144     dates ")
    checkdateDB=cursor_mysql.fetchall()
146
    checkdateDB=str(checkdateDB[0])
    checkdateDB=checkdateDB[1:-2]
148
    if (checkdate!=checkdateDB):
150         SQLdatetime=(" '"+datetime[1:6]+"-"+datetime[6:8]+"-"+datetime
[8:10]+" "+
152         datetime[14:16]+":"+datetime[16:18]+":"+datetime[18:21]+")"
        cursor_mysql.execute(insertCommandDate+SQLdatetime)
154
        fb_data=open(names[0], 'r')
156         for line1 in fb_data:
            replacedLine1=line1.replace("'", "'")
            detectorsInfo.append(replacedLine1)
158         fb_data.close()

```

```

160         detectorsID=detectorsInfo
162         for i in range(2,len(detectorsID)-1):
164             word=detectorsID[i].split(',')
166
167             laneNo=math.ceil((len(word)-2)/9)
168             if(i==len(detectorsID)-2):
169                 word[len(word)-1]=word[len(word)-1][: -2]
170                 laneNo=math.ceil((len(word)-1)/9)
172
173                 if(laneNo==1):
174                     detector=word[0]
176
177                     A="(SELECT 'detector_index' from 'detectors' WHERE '
178 detector_id='"+detector[1:]+"') ,"
179                     B="(SELECT 'date_index' from 'dates' WHERE 'date_time='"+
180 SQLdatetime+"') ,"
182
183                     lane1=[word[1], word[2], word[3], word[4], word[5], word[6],
184 word[7], word[8], word[9]]
185                     insertCommandValueLane1=(A+B+lane1[0]+","+",lane1[1]+","+",
186 lane1[2]+","+",lane1[3]+","+",lane1[4]+","+",lane1[5]+","+",lane1[6]+","+",lane1[7]+
187 ","+",lane1[8][: -1])
188
189                     insertCommandValueLane1="("+insertCommandValueLane1+")"
190
191                     cursor_mysql.execute(insertCommandDetectors+"("+detector
192 [1:]+"")
193
194                     cursor_mysql.execute(insertCommandLane1+
195 insertCommandValueLane1)
196
197                 elif(laneNo==2):
198                     detector=word[0]
199
200                     A="(SELECT 'detector_index' from 'detectors' WHERE '
201 detector_id='"+detector[1:]+"') ,"
202                     B="(SELECT 'date_index' from 'dates' WHERE 'date_time='"+
203 SQLdatetime+"') ,"
204
205                     lane1=[word[1], word[2], word[3], word[4], word[5], word[6],
206 word[7], word[8], word[9]]
207                     lane2=[word[10], word[11], word[12], word[13], word[14], word
208 [15], word[16], word[17], word[18]]
209
210                     insertCommandValueLane1=(A+B+lane1[0]+","+",lane1[1]+","+",
211 lane1[2]+","+",lane1[3]+","+",lane1[4]+","+",lane1[5]+","+",lane1[6]+","+",lane1[7]+
212 ","+",lane1[8])
213                     insertCommandValueLane2=(A+B+lane2[0]+","+",lane2[1]+","+",
214 lane2[2]+","+",lane2[3]+","+",lane2[4]+","+",lane2[5]+","+",lane2[6]+","+",lane2[7]+
215 ","+",lane2[8][: -1])
216
217                     insertCommandValueLane1="("+insertCommandValueLane1+")"

```

```

200         insertCommandValueLane2="( "+insertCommandValueLane2+" )"
202         cursor_mysql.execute(insertCommandDetectors+" (" +detector
[1:]+" )")
         cursor_mysql.execute(insertCommandLane1+
insertCommandValueLane1)
204         cursor_mysql.execute(insertCommandLane2+
insertCommandValueLane2)

206         elif(laneNo==3):
         detector=word[0]
208
         A="(SELECT 'detector_index' from 'detectors' WHERE '
detector_id'="+detector[1:]+"),"
210         B="(SELECT 'date_index' from 'dates' WHERE 'date_time'="+
SQLdatetime+"),"
212
         lane1=[word[1], word[2], word[3], word[4], word[5], word[6],
word[7], word[8], word[9]]
         lane2=[word[10], word[11], word[12], word[13], word[14], word
[15], word[16], word[17], word[18]]
214         lane3=[word[19], word[20], word[21], word[22], word[23], word
[24], word[25], word[26], word[27]]

216         insertCommandValueLane1=(A+B+lane1[0]+", "+lane1[1]+", "+
lane1[2]+", "+lane1[3]+", "+lane1[4]+", "+lane1[5]+", "+lane1[6]+", "+lane1[7]+
", "+lane1[8])
         insertCommandValueLane2=(A+B+lane2[0]+", "+lane2[1]+", "+
lane2[2]+", "+lane2[3]+", "+lane2[4]+", "+lane2[5]+", "+lane2[6]+", "+lane2[7]+
", "+lane2[8])
218         insertCommandValueLane3=(A+B+lane3[0]+", "+lane3[1]+", "+
lane3[2]+", "+lane3[3]+", "+lane3[4]+", "+lane3[5]+", "+lane3[6]+", "+lane3[7]+
", "+lane3[8][: -1])

220         insertCommandValueLane1="( "+insertCommandValueLane1+" )"
         insertCommandValueLane2="( "+insertCommandValueLane2+" )"
222         insertCommandValueLane3="( "+insertCommandValueLane3+" )"

224
226         cursor_mysql.execute(insertCommandDetectors+" (" +detector
[1:]+" )")
         cursor_mysql.execute(insertCommandLane1+
insertCommandValueLane1)
228         cursor_mysql.execute(insertCommandLane2+
insertCommandValueLane2)
         cursor_mysql.execute(insertCommandLane3+
insertCommandValueLane3)

230
232         elif(laneNo==4):
         detector=word[0]

234         A="(SELECT 'detector_index' from 'detectors' WHERE '
detector_id'="+detector[1:]+"),"
         B="(SELECT 'date_index' from 'dates' WHERE 'date_time'="+

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SQLdatetime+"),"
236
        lane1=[word [1] , word [2] , word [3] , word [4] , word [5] , word [6] ,
word [7] , word [8] , word [9]]
238
        lane2=[word [10] , word [11] , word [12] , word [13] , word [14] , word
[15] , word [16] , word [17] , word [18]]
        lane3=[word [19] , word [20] , word [21] , word [22] , word [23] , word
240
[24] , word [25] , word [26] , word [27]]
        lane4=[word [28] , word [29] , word [30] , word [31] , word [32] , word
[33] , word [34] , word [35] , word [36]]

242
        insertCommandValueLane1=(A+B+lane1 [0]+",",lane1 [1]+",",
lane1 [2]+",",lane1 [3]+",",lane1 [4]+",",lane1 [5]+",",lane1 [6]+",",lane1 [7]+
",",lane1 [8])
        insertCommandValueLane2=(A+B+lane2 [0]+",",lane2 [1]+",",
lane2 [2]+",",lane2 [3]+",",lane2 [4]+",",lane2 [5]+",",lane2 [6]+",",lane2 [7]+
",",lane2 [8])
244
        insertCommandValueLane3=(A+B+lane3 [0]+",",lane3 [1]+",",
lane3 [2]+",",lane3 [3]+",",lane3 [4]+",",lane3 [5]+",",lane3 [6]+",",lane3 [7]+
",",lane3 [8])
        insertCommandValueLane4=(A+B+lane4 [0]+",",lane4 [1]+",",
lane4 [2]+",",lane4 [3]+",",lane4 [4]+",",lane4 [5]+",",lane4 [6]+",",lane4 [7]+
",",lane4 [8][: -1])
246
        insertCommandValueLane1=" (" +insertCommandValueLane1+" )"
248
        insertCommandValueLane2=" (" +insertCommandValueLane2+" )"
        insertCommandValueLane3=" (" +insertCommandValueLane3+" )"
250
        insertCommandValueLane4=" (" +insertCommandValueLane4+" )"

252
        cursor_mysql.execute (insertCommandDetectors+" (" +detector
[1:]+" )" )

254
        cursor_mysql.execute (insertCommandLane1+
insertCommandValueLane1)
        cursor_mysql.execute (insertCommandLane2+
insertCommandValueLane2)
256
        cursor_mysql.execute (insertCommandLane3+
insertCommandValueLane3)
        cursor_mysql.execute (insertCommandLane4+
insertCommandValueLane4)

258
        elif (laneNo==5):
260
            detector=word [0]

262
            A="(SELECT 'detector_index' from 'detectors' WHERE '
detector_id '='+detector [1:]+" )" ,
            B="(SELECT 'date_index' from 'dates' WHERE 'date_time '='+
SQLdatetime+"),"
264

        lane1=[word [1] , word [2] , word [3] , word [4] , word [5] , word [6] ,
word [7] , word [8] , word [9]]
266
        lane2=[word [10] , word [11] , word [12] , word [13] , word [14] , word
[15] , word [16] , word [17] , word [18]]
        lane3=[word [19] , word [20] , word [21] , word [22] , word [23] , word
[24] , word [25] , word [26] , word [27]]

```



```

268         lane4=[word [28] , word [29] , word [30] , word [31] , word [32] , word
[33] , word [34] , word [35] , word [36]]
        lane5=[word [37] , word [38] , word [39] , word [40] , word [41] , word
[42] , word [43] , word [44] , word [45]]
270
        insertCommandValueLane1=(A+B+lane1 [0]+"," +lane1 [1]+"," +
lane1 [2]+"," +lane1 [3]+"," +lane1 [4]+"," +lane1 [5]+"," +lane1 [6]+"," +lane1 [7]+
"," +lane1 [8])
272        insertCommandValueLane2=(A+B+lane2 [0]+"," +lane2 [1]+"," +
lane2 [2]+"," +lane2 [3]+"," +lane2 [4]+"," +lane2 [5]+"," +lane2 [6]+"," +lane2 [7]+
"," +lane2 [8])
        insertCommandValueLane3=(A+B+lane3 [0]+"," +lane3 [1]+"," +
lane3 [2]+"," +lane3 [3]+"," +lane3 [4]+"," +lane3 [5]+"," +lane3 [6]+"," +lane3 [7]+
"," +lane3 [8])
274        insertCommandValueLane4=(A+B+lane4 [0]+"," +lane4 [1]+"," +
lane4 [2]+"," +lane4 [3]+"," +lane4 [4]+"," +lane4 [5]+"," +lane4 [6]+"," +lane4 [7]+
"," +lane4 [8])
        insertCommandValueLane5=(A+B+lane5 [0]+"," +lane5 [1]+"," +
lane5 [2]+"," +lane5 [3]+"," +lane5 [4]+"," +lane5 [5]+"," +lane5 [6]+"," +lane5 [7]+
"," +lane5 [8][: -1])
276
        insertCommandValueLane1=" (" +insertCommandValueLane1+" )"
278        insertCommandValueLane2=" (" +insertCommandValueLane2+" )"
        insertCommandValueLane3=" (" +insertCommandValueLane3+" )"
280        insertCommandValueLane4=" (" +insertCommandValueLane4+" )"
        insertCommandValueLane5=" (" +insertCommandValueLane5+" )"
282
284
        cursor_mysql.execute (insertCommandDetectors+" (" +detector
[1:]+" )" )
286        cursor_mysql.execute (insertCommandLane1+
insertCommandValueLane1)
        cursor_mysql.execute (insertCommandLane2+
insertCommandValueLane2)
288        cursor_mysql.execute (insertCommandLane3+
insertCommandValueLane3)
        cursor_mysql.execute (insertCommandLane4+
insertCommandValueLane4)
290        cursor_mysql.execute (insertCommandLane5+
insertCommandValueLane5)
292
        elif (laneNo==6):
294            detector=word [0]
            A="(SELECT 'detector_index' from 'detectors' WHERE '
detector_id'="+detector [1:]+" )" ,
296            B="(SELECT 'date_index' from 'dates' WHERE 'date_time'="+
SQLdatetime+" )" ,
298            lane1=[word [1] , word [2] , word [3] , word [4] , word [5] , word [6] ,
word [7] , word [8] , word [9]]
            lane2=[word [10] , word [11] , word [12] , word [13] , word [14] , word
[15] , word [16] , word [17] , word [18]]
300            lane3=[word [19] , word [20] , word [21] , word [22] , word [23] , word

```

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[24] , word [25] , word [26] , word [27]]
        lane4=[word [28] , word [29] , word [30] , word [31] , word [32] , word
[33] , word [34] , word [35] , word [36]]
302        lane5=[word [37] , word [38] , word [39] , word [40] , word [41] , word
[42] , word [43] , word [44] , word [45]]
        lane6=[word [46] , word [47] , word [48] , word [49] , word [50] , word
[51] , word [52] , word [53] , word [54]]
304
        insertCommandValueLane1=(A+B+lane1 [0]+"," ,"+lane1 [1]+"," ,"+
lane1 [2]+"," ,"+lane1 [3]+"," ,"+lane1 [4]+"," ,"+lane1 [5]+"," ,"+lane1 [6]+"," ,"+lane1 [7]+
"," ,"+lane1 [8])
306        insertCommandValueLane2=(A+B+lane2 [0]+"," ,"+lane2 [1]+"," ,"+
lane2 [2]+"," ,"+lane2 [3]+"," ,"+lane2 [4]+"," ,"+lane2 [5]+"," ,"+lane2 [6]+"," ,"+lane2 [7]+
"," ,"+lane2 [8])
        insertCommandValueLane3=(A+B+lane3 [0]+"," ,"+lane3 [1]+"," ,"+
lane3 [2]+"," ,"+lane3 [3]+"," ,"+lane3 [4]+"," ,"+lane3 [5]+"," ,"+lane3 [6]+"," ,"+lane3 [7]+
"," ,"+lane3 [8])
308        insertCommandValueLane4=(A+B+lane4 [0]+"," ,"+lane4 [1]+"," ,"+
lane4 [2]+"," ,"+lane4 [3]+"," ,"+lane4 [4]+"," ,"+lane4 [5]+"," ,"+lane4 [6]+"," ,"+lane4 [7]+
"," ,"+lane4 [8])
        insertCommandValueLane5=(A+B+lane5 [0]+"," ,"+lane5 [1]+"," ,"+
lane5 [2]+"," ,"+lane5 [3]+"," ,"+lane5 [4]+"," ,"+lane5 [5]+"," ,"+lane5 [6]+"," ,"+lane5 [7]+
"," ,"+lane5 [8])
310        insertCommandValueLane6=(A+B+lane6 [0]+"," ,"+lane6 [1]+"," ,"+
lane6 [2]+"," ,"+lane6 [3]+"," ,"+lane6 [4]+"," ,"+lane6 [5]+"," ,"+lane6 [6]+"," ,"+lane6 [7]+
"," ,"+lane6 [8][: -1])
312
        insertCommandValueLane1=" (" +insertCommandValueLane1+" )"
        insertCommandValueLane2=" (" +insertCommandValueLane2+" )"
314        insertCommandValueLane3=" (" +insertCommandValueLane3+" )"
        insertCommandValueLane4=" (" +insertCommandValueLane4+" )"
316        insertCommandValueLane5=" (" +insertCommandValueLane5+" )"
        insertCommandValueLane6=" (" +insertCommandValueLane6+" )"
318
        cursor_mysql.execute (insertCommandDetectors+" (" +detector
[1:]+" )" )
320
        cursor_mysql.execute (insertCommandLane1+
insertCommandValueLane1)
322        cursor_mysql.execute (insertCommandLane2+
insertCommandValueLane2)
        cursor_mysql.execute (insertCommandLane3+
insertCommandValueLane3)
324        cursor_mysql.execute (insertCommandLane4+
insertCommandValueLane4)
        cursor_mysql.execute (insertCommandLane5+
insertCommandValueLane5)
326        cursor_mysql.execute (insertCommandLane6+
insertCommandValueLane6)
328
        elif (laneNo==7):
            detector=word [0]
330
            A="(SELECT 'detector_index' from 'detectors' WHERE '
detector_id'="+detector [1:]+" )" ,

```

```

332         B="(SELECT 'date_index' from 'dates' WHERE 'date_time'="+
SQLdatetime+"),"
334         lane1=[word [1] , word [2] , word [3] , word [4] , word [5] , word [6] ,
word [7] , word [8] , word [9]]
        lane2=[word [10] , word [11] , word [12] , word [13] , word [14] , word
[15] , word [16] , word [17] , word [18]]
336         lane3=[word [19] , word [20] , word [21] , word [22] , word [23] , word
[24] , word [25] , word [26] , word [27]]
        lane4=[word [28] , word [29] , word [30] , word [31] , word [32] , word
[33] , word [34] , word [35] , word [36]]
338         lane5=[word [37] , word [38] , word [39] , word [40] , word [41] , word
[42] , word [43] , word [44] , word [45]]
        lane6=[word [46] , word [47] , word [48] , word [49] , word [50] , word
[51] , word [52] , word [53] , word [54]]
340         lane7=[word [55] , word [56] , word [57] , word [58] , word [59] , word
[60] , word [61] , word [62] , word [63]]

342         cursor_mysql.execute(insertCommandDetectors+" (" +detector
[1:]+" ")")

344         insertCommandValueLane1=(A+B+lane1 [0] + " , " +lane1 [1] + " , " +
lane1 [2] + " , " +lane1 [3] + " , " +lane1 [4] + " , " +lane1 [5] + " , " +lane1 [6] + " , " +lane1 [7] +
" , " +lane1 [8])
        insertCommandValueLane2=(A+B+lane2 [0] + " , " +lane2 [1] + " , " +
lane2 [2] + " , " +lane2 [3] + " , " +lane2 [4] + " , " +lane2 [5] + " , " +lane2 [6] + " , " +lane2 [7] +
" , " +lane2 [8])
346         insertCommandValueLane3=(A+B+lane3 [0] + " , " +lane3 [1] + " , " +
lane3 [2] + " , " +lane3 [3] + " , " +lane3 [4] + " , " +lane3 [5] + " , " +lane3 [6] + " , " +lane3 [7] +
" , " +lane3 [8])
        insertCommandValueLane4=(A+B+lane4 [0] + " , " +lane4 [1] + " , " +
lane4 [2] + " , " +lane4 [3] + " , " +lane4 [4] + " , " +lane4 [5] + " , " +lane4 [6] + " , " +lane4 [7] +
" , " +lane4 [8])
348         insertCommandValueLane5=(A+B+lane5 [0] + " , " +lane5 [1] + " , " +
lane5 [2] + " , " +lane5 [3] + " , " +lane5 [4] + " , " +lane5 [5] + " , " +lane5 [6] + " , " +lane5 [7] +
" , " +lane5 [8])
        insertCommandValueLane6=(A+B+lane6 [0] + " , " +lane6 [1] + " , " +
lane6 [2] + " , " +lane6 [3] + " , " +lane6 [4] + " , " +lane6 [5] + " , " +lane6 [6] + " , " +lane6 [7] +
" , " +lane6 [8])
350         insertCommandValueLane7=(A+B+lane7 [0] + " , " +lane7 [1] + " , " +
lane7 [2] + " , " +lane7 [3] + " , " +lane7 [4] + " , " +lane7 [5] + " , " +lane7 [6] + " , " +lane7 [7] +
" , " +lane7 [8][: -1])

352         insertCommandValueLane1=" (" +insertCommandValueLane1+" )"
        insertCommandValueLane2=" (" +insertCommandValueLane2+" )"
354         insertCommandValueLane3=" (" +insertCommandValueLane3+" )"
        insertCommandValueLane4=" (" +insertCommandValueLane4+" )"
356         insertCommandValueLane5=" (" +insertCommandValueLane5+" )"
        insertCommandValueLane6=" (" +insertCommandValueLane6+" )"
358         insertCommandValueLane7=" (" +insertCommandValueLane7+" )"

360         cursor_mysql.execute(insertCommandLane1+
insertCommandValueLane1)
        cursor_mysql.execute(insertCommandLane2+
insertCommandValueLane2)

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```

362         sql.execute(insertCommandLane3+insertCommandValueLane3)
           cursor_mysql.execute(insertCommandLane4+
insertCommandValueLane4)
364         cursor_mysql.execute(insertCommandLane5+
insertCommandValueLane5)
           cursor_mysql.execute(insertCommandLane6+
insertCommandValueLane6)
366         cursor_mysql.execute(insertCommandLane7+
insertCommandValueLane7)

368         else:
           print("new lane is established")
370           print(laneNo)

372     else:
           print("Duplicated date: data already inserted")
374
376     ## closing connection
376     cnx.commit()
           print("fast_realtime3: disconnecting...")
378     cnx.close()

380
382     ##### main section#####
382     #fileName=realtime_data_collector()
384     a=os.getcwd()
           os.chdir(a+"/realtime_files")
386     names=realtime_data_collector()
           ##names=["May_31_01_08_r.sql","May_31_01_08_r_stamp.sql"]
388     fileName=names
           parsingDetectors(fileName)
390     os.remove(names[0])
           os.remove(names[1])
392     print(names[0]+" and "+ names[1]+" have been deleted")

```

Appendix E

Congestion Prediction Script

A Python script was developed to provide early prediction of congestion events using machine learning techniques. During a training phase, historical data during the Winter season of 2014 was used to train a decision tree classifier able to predict oncoming congestion reliably up to 10 minutes early using four minutes of past traffic measurements.

The code for the script is provided below:

```
#!/usr/bin/python
2 import csv
  import array
4 #import numpy

6 #READING SENSORS.CSV FILE

8 ifile=open('sensors.csv', 'rU');
  reader = csv.reader(ifile, delimiter=',');
10 counter=0
  for row in reader:
12     counter = counter +1;
  ifile.close()
14

16 #parameter setting
  rownum = 0
18 minbak=4
  count_b=[0,0,0,0,0] # count value in 5 min back from current time
20 occupancy_b=[0,0,0,0,0] # occupancy value in 5 min back
  speed_b=[0,0,0,0,0] # speed value in 5 min back from current time
22 decision=[0]*(counter-1) # conjection prediction 4 min ahead of current time
  #0 FOR NON CONGESTION AND 1 FOR CONGESTION
24

  ifile=open('sensors.csv', 'rU');
26 reader = csv.reader(ifile, delimiter=',')

28 for row in reader:
  #print('TEST')
30 # Save header row.
  if rownum == 0:
32     header = row

34     elif rownum<6:
```

```

colnum = 0
36 for col in row:
    if ((colnum>2)and(colnum<10)):
38         count_b[5-rownum]=count_b[5-rownum]+int(col)
    elif (colnum==10):
40         occupancy_b[5-rownum]=occupancy_b[5-rownum]+int(col)
    elif colnum==11:
42         speed_b[5-rownum]=speed_b[5-rownum]+int(col)
        colnum += 1
44 else:
    #IMPLEMENTING THE J-48 DECISION TREE
46     if speed_b[0] > 36.4:
        con=0
48     elif count_b[0] > 20:
        con=1
50     elif occupancy_b[0] > 29:
        if speed_b[4] > 12.6:
52             con=0
        else:
54             con=1
    elif occupancy_b[2] <= 9.6:
56         con=0
    elif (occupancy_b[3] >= 13.8):
58         con=0
    elif speed_b[3] > 30.6:
60         con=0
    elif count_b[3] > 13.6:
62         con=0
    else:
64         con=1
    decision [rownum-5]=con
66
    for k in range(4, -1, -1):
68         count_b[k]=count_b[k-1]
        occupancy_b[k]=occupancy_b[k-1]
70         speed_b[k]=speed_b[k-1]

72 count_b[0]=0
    occupancy_b[0]=0
74 speed_b[0]=0

76 for col in row:
    if ((colnum>2)and(colnum<10)):
78         count_b[0]=count_b[0]+int(col)
    elif (colnum==10):
80         occupancy_b[0]=occupancy_b[0]+int(col)
    elif colnum==11:
82         speed_b[0]=speed_b[0]+int(col)
        colnum += 1
84 rownum += 1
ifile.close()
86 print (decision)
"""
88 print (count_b)
print ("\n")

```

```
90 print (occupancy_b)
    print ("\n")
92 print (speed_b)
   """
```



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