Vehicle Detector Concept of Operations

Virginia Department of Transportation Northern Region Operations

FINAL

Prepared by:

Kimley-Horn and Associates, Inc.

May 14, 2008

Table of Contents

1 Scope **1**
1.1 Identification 1
1.2 Role of the Concept of Operations within the Systems Engineering Process 1
1.3 System Overview 2
1.4 Goals and Objectives 4
1.5 Vision for the System 5

2 Referenced Documents **5**

3 User-Oriented Operational Description **7**
3.1 Description of the Existing System 7
3.2 Stakeholders and their Roles and Responsibilities 12

4 Operational Needs **14**
4.1 VDOT NRO Traffic Management Center Operators 14
4.2 VDOT NRO Freeway Engineers 15
4.3 VDOT NRO Traffic Signal Operations Engineers 17
4.4 VDOT Continuous Count Program 17
4.5 VDOT NRO Maintenance Division 17
4.6 VDOT NRO Traffic Engineering 18
4.7 VDOT NoVA, Fredericksburg, and Culpeper District Transportation Planning 18
4.8 Private Sector 18
4.9 Program Managers 18
4.10 Regional Media Outlets 19

5 System Overview **19**
5.1 Relationship with Other Systems 19
5.2 Summary of Device Locations 20
5.3 Communication Requirements 21
5.4 Software Requirements 22
5.5 Project Architecture 22
5.6 Other Projects that may Affect, Enhance, or Provide Opportunities 23
5.7 Constructability Considerations 26

6 Operational and Support Environment **26**
6.1 Personnel 26
6.2 Facilities 27
6.3 Hardware and Software 27
6.4 Operating Procedures 27
6.5 Maintenance 27

7 Operational Scenarios **28**
7.1 Freeway Traffic Management (Non-incident) Scenario 28
7.2 Freeway Incident Management Scenario 28
7.3 Recurring Bottleneck Scenario 29

7.4 Evaluate HOV lanes hours of operation 29
7.5 Evaluate effectiveness of traffic control 29
7.6 Performance Measures Reports 30
7.7 Failed Device Scenario 30

8 Next Steps 30

8.1 Detailed Requirements 31
8.2 System Design 31
8.3 Software/Hardware Development Field Installation 31
8.4 Unit/Device Testing 32
8.5 Subsystem & System Verification and Acceptance 32
8.6 System Validation 33
8.7 Operations & Maintenance 33

List of Figures

Figure 1. The Systems Engineering Process 2
Figure 2. Existing Active Detector Locations in Northern Virginia 9
Figure 3. Dashboard Screenshot 11
Figure 4. Aggregating Traffic Detector Data to Different Geographic Sites 21
Figure 5. VDOT NOVA STC Field Equipment Interconnect Diagram 22

List of Tables

Table 1. Goals and Objectives from 2006 NOVA Smart Travel Program Plan 4
Table 2. Existing Detector Stations and Zones by Route 8

Appendices

Appendix A. High-Level Requirements A-1
Appendix B. NRO ITS Barcode Requirements B-1
Appendix C. System Validation Plan C-1

1 Scope

1.1 Identification

This Concept of Operations presents a plan for the vehicle detection system in the VDOT Northern Region Operations (NRO). In the development of this document, several stakeholders were interviewed in one-on-one or small group settings, in order to understand the breadth of current use and future need for vehicle detection. In most cases, this constitutes the need for the data obtained through detection although there are also needs with respect to the maintenance of the field infrastructure and the provision of traveler information. This document is focused on freeway operations and integrated freeway and arterial corridor traffic management and does not address the needs for stop bar detection at intersections or traffic counts to support signal timing.

A great deal of work has been done recently to determine the status of existing detectors, identify NRO's detector needs, and plan for future deployments based on those needs. This document assimilates these inputs into a single document that can be used as a guide for future deployments. Its focus, however, will not be on the type of technology deployed, although that may be a factor for maintenance. Rather, it will look at the traffic data needs of the different prospective users and develop requirements for future detection deployments.

In conjunction with this Concept of Operations, a map-based master plan will be developed that will identify detector needs by corridor and attempt to prioritize the order in which deployments should take place. This master planning effort is being done in concert with master plans for Dynamic Message Sign (DMS) units and Closed Circuit Television (CCTV) units, and many of the prioritization factors such as congestion and the availability of alternate routes, are shared between these different ITS subsystems. For detection, however, there may be different specific needs on different corridors and the master plan will identify these corridor-specific needs.

1.2 Role of the Concept of Operations within the Systems Engineering Process

A Concept of Operations is the critical first step in the systems engineering process, which is mandated by the Federal Highway Administration (FHWA) for ITS projects using federal funding per the Final Rule on ITS Architecture and Standards, found in 23 CFR 940 of SAFETEA-LU. The systems engineering process can be represented by the "V" Diagram in **Figure 1**. Regardless of whether it is a requirement for federal funding, the process is important to ensure the system or technology being designed and deployed meets the needs of its end users and serves the purposes for which it was intended.

The Concept of Operations presents the users' perspective on how the system will help meet VDOT business objectives. The term "system" can be as simple as a single vehicle detector or as complex as a multi-million dollar software application. The scope and detail of a Concept of Operations should be commensurate with the complexity of the system being deployed. In addition, it presents the case for the new system in the context of the current environment and defines any external dependencies that may affect, or be affected by, the system under consideration.

Written from the user's perspective, a Concept of Operations is designed to be reviewed and validated by the system users who may not necessarily have a detailed understanding of the underlying technologies or design considerations. The user needs lead to system requirements, which are used to design the system. Once the system is designed and implemented, the process proceeds up the right side of the "V," where the system is validated against the requirements and the Concept of Operations to confirm that it is designed appropriately to meet the objectives for which it was intended. By linking the integration steps (the right side of the "V") with the definition steps (the left side of the "V"), the system can be tested and verified early and often to reduce the risk that the final product does not meet expectations.

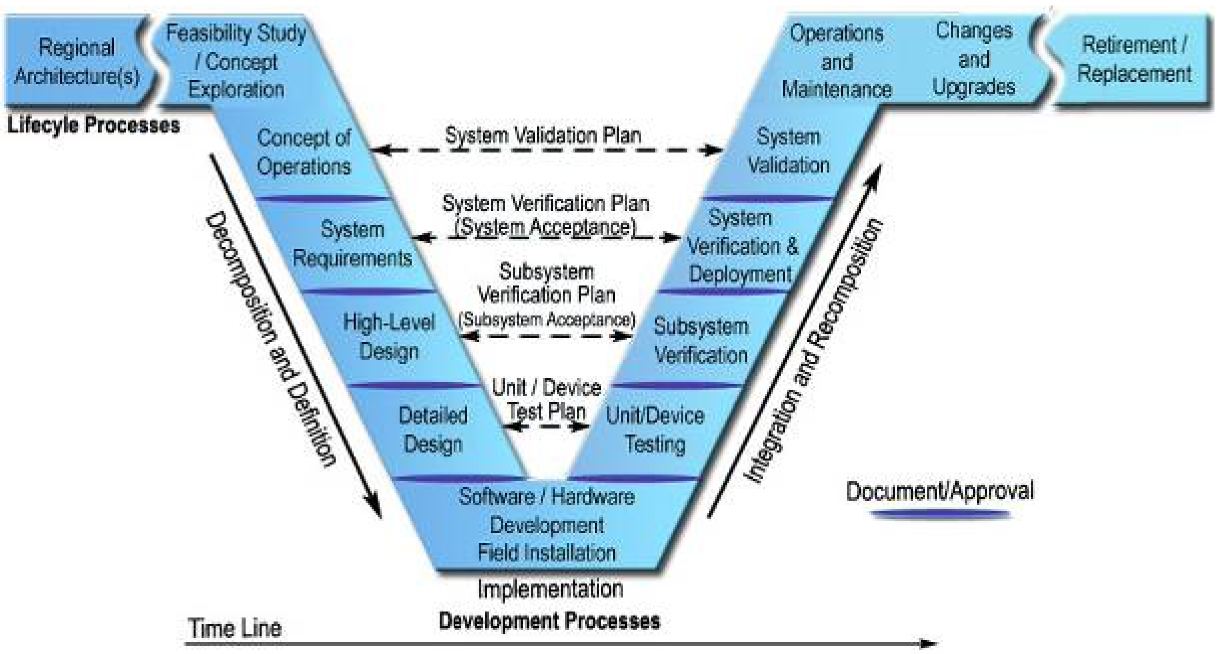

Figure 1. The Systems Engineering Process

1.3 System Overview

Accurate data describing the status of the transportation network is the backbone of system operations management. Without accurate data, traffic engineers cannot optimize signal phasing and timing, effective incident management cannot be undertaken, decisions regarding managed lanes operations cannot be made effectively, and information cannot be shared with the traveling public. With the establishment of system operations as a core function within VDOT, a new focus is being placed on ways to measure performance that are both meaningful to the public and useful to system management and planning purposes. Travel time is considered by many to be a critical measure that has the potential to serve many needs.

For purposes of this document, the detection system includes the collective deployment of sensors that directly measure traffic flow data such as speed, volume, occupancy, vehicle classification or travel time. Two types of detection are discussed in more detail below – point detection and probe-vehicle detection.

1.3.1 Point vs. Probe Vehicle Detection

Point detection measures averages of these parameters for the traffic stream and is aggregated over intervals such as 20-seconds or 5-minutes. The most common type of point detector has historically been inductive loops, though various non-intrusive detectors have gained popularity in recent years. Regardless of the technology, these detectors measure traffic at a fixed point. For purposes of this Concept of Operations, which is meant to be as technology-independent as possible, the emphasis on detector types is the data they capture. It must be noted, however, that a single type of detector cannot currently capture all traffic flow parameters.

The limitation of point sensors is that they do not capture conditions between sensors. While it is typically a reasonable assumption that conditions over a homogenous section of road will be similar, bottlenecking behavior and off-ramp queues will lead to some inaccuracies in extrapolating point speeds over a segment to derive travel times. However, point sensors can capture typical traffic parameters such as: speed, volume, occupancy, and vehicle classification.

Probe vehicle-type detection tracks individual vehicles from one point to the next. These may include: toll tag readers, license plate readers, cell phone tracking technologies or GPS tracking technologies. This type of data collection generally does not capture every vehicle and therefore does not measure complete traffic volume. Instead, it measures the speed or point-to-point travel time of a sample of individual vehicles. Toll tag readers or license plate readers are installed at fixed locations and identify vehicles as they pass by. While this provides the exact travel time of individual vehicles between readers, there is inherent latency in that measurement.

An alternative probe technology is GPS tracking which polls the equipped vehicles for their instantaneous speed and aggregates these measurements over a segment or roadway. While this does not measure travel times directly, it is likely to be more accurate for real-time applications. It should be noted that probe detection could potentially introduce privacy concerns among drivers. Probe vehicle techniques involve tracking vehicles as they travel the freeway and arterial street system. This often raises concerns that motorists may be more likely to receive traffic citations or have their travel habits monitored.

1.3.2 Freeway vs. Arterial Detection

In addition to the freeway applications that are the focus of this Concept of Operations, detectors are obviously a longstanding and important part of arterial traffic signal operations. At intersections in NRO, they are used for actuated traffic signal control and for volume counts to support signal timing. These applications are mature and the needs are well known. For this reason, they are not addressed in detail in this document. However, similar needs for traveler information and performance measurement apply to arterials as well as freeways, but there are important differences in the way arterial flow data is measured and understood.

Travel times are more common on freeways than on arterials because it is possible to extrapolate point detector speed data—which is commonplace—into link travel times. On freeways, these links are generally delineated over distances where volumes and geometry are homogenous, such as from one interchange to the next. For arterials, however, point speed data is not translatable into travel times because links are not homogenous. Rather, travel times are driven by traffic signal delays. A point detector will either show stopped or freely flowing traffic on an arterial link depending on where it is relative to the back of the stop bar queue.

In contrast to point detection, probe vehicle detection can effectively derive point-to-point travel times on arterials. Probe vehicle detectors (e.g., toll tag readers or license plate readers) can be placed at successive intersections. This provides a travel time between intersections, which can be decomposed into the free flow travel time on the link and the intersection delay. The limitation to probe data collection of this type, however, is latency, which is magnified at traffic signals with long cycle times.

For performance measures, link travel time and volume provides a comprehensive picture for that link: the number of vehicles served and the per-vehicle delay. Travel time alone does not indicate number of vehicles served within the given delay. An improvement in either delay or throughput represents an improvement in operational performance.

1.4 Goals and Objectives

Based on existing documentation from VDOT NRO's Freeway Engineering group, the following goals and objectives for the detector system are as follows:

1. Provide the ability to measure the performance of the transportation system
2. Allow monitoring of real-time performance of the system and specific subsystems, e.g., ramp meters and lane control systems, at the link level
3. Support real-time traveler information and traffic prediction, e.g., travel time

The 2006 NOVA Smart Travel Program Plan adds the following additional goals and objectives that relate to detectors:

Table 1. Goals and Objectives from 2006 NOVA Smart Travel Program Plan

OBJECTIVES	STRATEGIES
Goal 1: Enhance Public Safety	
1.A – Minimize Incidents	▪ Integrate with "sources" of incident information, such as CAD systems, to speed incident detection and response (CAD Integration).
1.B – Respond Efficiently to Incidents	▪ Improve and expand detection capability through new technologies, partnerships, and improvements to existing systems.
1.C – Improve Transportation Security	▪ Efficiently share accurate and timely travel condition, roadway closure, routing, and other information with the public during emergency transportation operations.
Goal 2: Enhance Mobility	
2.A – Operate the Transportation System Effectively and Efficiently	▪ Maximize the use of the transportation system capacity to move traffic. Detailed traffic and roadway conditions data are vital for NRO to assess the performance of the roadway network and allow for more proactive traffic management. ▪ Proactively monitor and assess the condition of the freeway, primary, and secondary road system in real-time regarding: safety, congestion, travel information, incident detection/response, traffic volume, speed, and capacity.

2.C – Expand ITS Infrastructure to Enable Corridor Management	▪ Implement coordinated, corridor-level traffic management on key freeway segments and adjacent arterial routes. ▪ Expand the geographic coverage of ITS infrastructure on the NRO arterial and freeway transportation system, including but not limited to ITS and traffic signal systems, freeway lighting system, CCTV system, variable message boards, incident detection system, condition monitoring system, vehicle classification system, ramp-metering system, gate control system, and others.
Goal 3: Make the Transportation System User Friendly	
3.B – Support Traveler Information Services	▪ Effectively provide data and facilitate multi-modal real-time traffic information for the public so that travelers may select the most effective mode, route and travel time choices.

1.5 Vision for the System

VDOT NRO's vision for its Detection System is provided below:

> The VDOT Northern Region Operations Detection System will provide the ability to measure the performance of the transportation system, allow monitoring of the real-time performance of the system and specific subsystems, and support real-time traveler information and near-term traffic forecasting. The system will allow Traffic Management Center (TMC) operators to actively manage traffic through HOV lanes, shoulder lanes and other means, and proactively manage corridors of freeways and arterials. Detection data will be shared with appropriate regional, statewide, and private sector stakeholders to improve interagency coordination and deliver real-time traveler information including travel times.

The system envisioned in this Concept of Operations combines upgrades to the existing system's detection equipment, detection infill within the existing system's instrumented corridors, and installation of new field equipment to expand coverage to new areas within the region. It is not limited to agency-owned detection infrastructure, but rather includes other sources of traffic data including the private sector.

The new detection system should enhance the benefits that the existing infrastructure provides its users while providing adequate coverage to new key areas through expansion. The detection system will be an integral part of the regional ITS network operated through a combination of automated control by Advanced Traffic Management System (ATMS) software and human operators at the Public Safety Transportation Operations Center (PSTOC) TMC.

2 Referenced Documents

Traffic detectors are merely one component of VDOT NRO's Intelligent Transportation System (ITS) and likewise, this Concept of Operations must be consistent with other related work. Several concurrent efforts and their relationship to this Concept of Operations are described in this section. In addition, this document builds on past work on the state and future direction of detectors in the Northern Region; that work is referenced here as well.

- Go-Forward Plan (2005). This document provides an evaluation of the existing software, hardware, and field devices, an assessment of state of the practice and a series of recommendations.

- NoVA Smart Travel Program Plan Update (2006). This document identifies VDOT NRO's overall vision, goals and objectives, ITS-related needs identified by stakeholders, and the regional operating concept.

- VDOT NRO Freeway Engineering White Papers. A number of white papers have been written by NRO's Freeway Engineering group on the existing status of detectors, needs, and proposed future direction for detectors. These documents supplemented and confirmed input from the stakeholder input meetings; they also get into detailed topics on detector technologies and implementation details that this Concept of Operations does not address.

- VDOT NRO ATMS Concept of Operations (concurrent). At the same time as this document is being written, VDOT NRO is in the process of replacing its ATMS software. As part of that project an ATMS Concept of Operations has been developed, which defines the majority of the activities being performed by the TMC.

- VDOT NRO DMS Concept of Operations (concurrent). In a parallel effort, VDOT NRO is developing a Concept of Operations for DMS. One of the primary operational needs for DMS, as indentified in this document, is the posting of travel times. There is a clear relationship between the posting of travel times and the detection required to collect the data required to calculate travel times.

- VDOT NRO CCTV Concept of Operations (concurrent). In a parallel effort, VDOT NRO is developing a Concept of Operations for CCTV cameras. This work is being performed under the same contract as this detection Concept of Operations and the stakeholder information gathering meetings were held jointly in most cases.

- ITS Upgrade and Expansion Corridor Priority Development (2008). In support of its DMS, CCTV and Detector Master Plans, VDOT NRO recently completed an effort to prioritize corridors for ITS deployment. This prioritization will be used for a forthcoming Detector Master Plan, which will be a follow on to this Concept of Operations.

- Inventory of System Operations Data Collection and Use in the Virginia Department of Transportation (2006). This document was developed by the Virginia Transportation Research Council to assess the needs for archived detector data statewide. It defined several detector needs by stakeholder group and supplemented and confirmed input from the stakeholder input meetings.

- VDOT NRO TMC / Camp 30-to-PSTOC Transition Plan (2007). This document discusses the transition from the existing NRO TMC to the PSTOC. It describes the communications between the PSTOC and field equipment.

- VDOT Northern Region Operations Standard Operating Procedures (2007). This document defines VDOT NRO Traffic Management Center (TMC) standard operating procedures.

- Interviews with Stakeholders (2008). In developing the Concept of Operations, several one-on-one and group meeting were held to identify stakeholder needs. Input was received from the following stakeholders:

  - VDOT NRO Freeway Operations
  - VDOT NRO Signal System Operations
  - VDOT NRO Maintenance
  - VDOT NRO Systems Engineering
  - VDOT NRO Traffic Engineering
  - VDOT NRO Planning & Programming
  - VDOT NoVA Transportation Planning
  - VDOT Central Office – Continuous Counts Program
  - Virginia Transportation Research Council (VTRC) and the University of Virginia

3 User-Oriented Operational Description

3.1 Description of the Existing System

VDOT NRO's existing detection system was originally designed to support the following functional subsystems:

- **Incident Detection System (IDS)**
  The IDS is designed to supply detection data to algorithms that would automatically alert TMC Operators of incidents, via the ATMS software. The IDS never functioned as intended; it generated too many false positives and became a nuisance to the TMC Operators, who had the alert functionality turned off. This is consistent with what has been found across the country—in urban areas with recurring congestion, incident detection algorithms have had difficulty producing reliable alerts in a reasonable amount of time.

- **Condition Monitoring System (CMS)**
  The CMS was designed to provide TMC Operators with a congestion map (red, yellow, green) via the ATMS software. Lacking a mission-critical application to justify the maintenance expense, the detectors that supported it fell into further and further disrepair, their data became unreliable and the congestion map was no longer meaningful to TMC Operators.

- **Ramp Metering System (RMS)**
  Detection for the ramp metering system is designed to feed the ramp metering systems which regulate the number of vehicles entering an interstate in order to keep mainline traffic flow in the stable region to minimize congestion. Ramp meters, and the detectors that are connected to the system through ramp metering controllers, are confined to I-66 and I-395 inside the Capital Beltway.

The combined IDS, CMS, and RMS subsystems consist of over 380 stations comprising nearly 1000 point detectors **Table 1**, **Figure 2,** and **Figure 2a** provide a high-level view of the locations of existing devices within NRO. While there are several detectors on I-495, nearly all of these are inactive or decommissioned except for a few clustered around the Springfield Interchange; the vast majority of active detectors are on I-66, I-95 and I-395. Existing detection on I-66 extends out to the Fairfax/Prince William county line; detection on I-95 extends to Aquia in Stafford County. While not maintained by NRO, VDOT has a number of continuous count stations in the region that are used for statewide traffic volume and vehicle classification reporting.

Table 2. Existing Detector Stations and Zones by Route

Route	Approx Miles*	Active Stations	Active Zones
I-395	19	31	186
I-495	42	17	79
I-66	54	221	389
I-95	38	111	285

** - Mileage is approximate and only considers the lengths of I-66 and I-95 with existing detection*

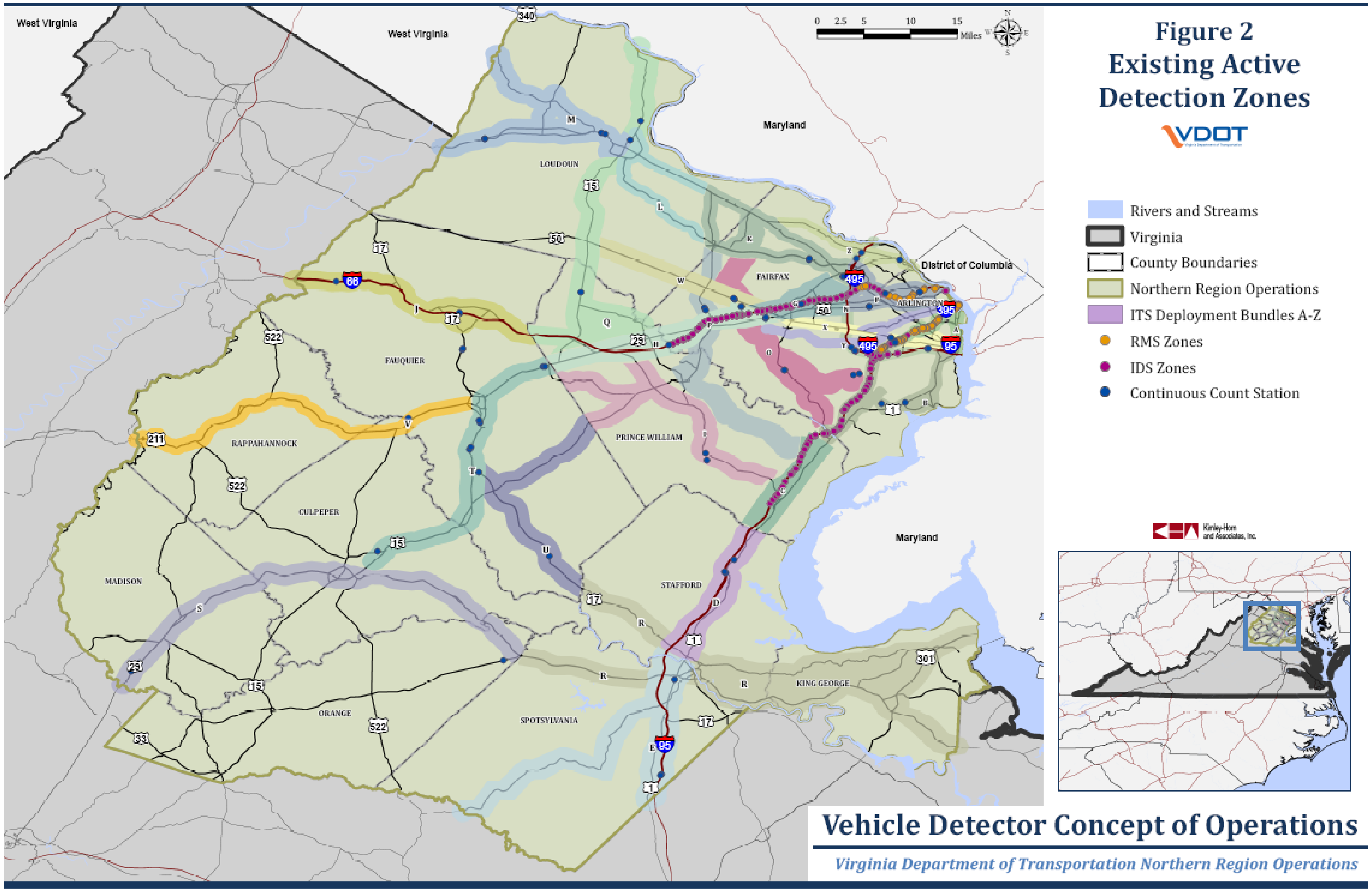

Figure 2. Existing Active Detector Locations in Northern Virginia

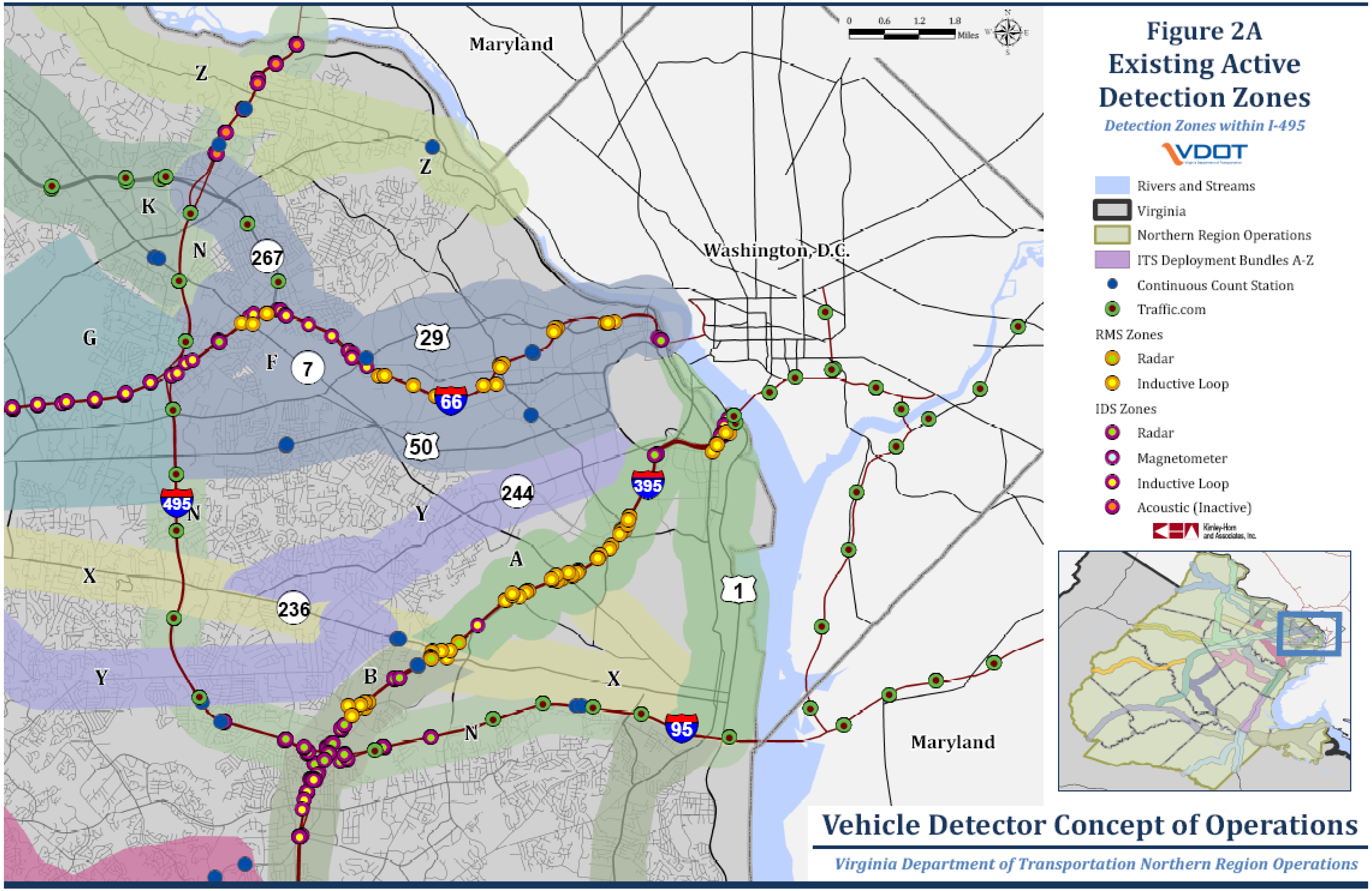

Figure 2A. Existing Detector Location in Northern Virginia (Zoomed)

Over time the IDS and CMS subsystems fell into disrepair. Currently, the remnants of the IDS and CMS detection system's main use are to supply a limited amount of detector data to external entities for research, mobility performance measurement, and third-party traveler information services. These include the University of Virginia, Virginia Tech, the Federal Highway Administration (FHWA), and private companies including Trichord, TrafficCast, Inrix, SpeedInfo, and Traffic.com. The single largest constraint on the existing detection system is its inability to provide reliable data.

Recently, VDOT NRO has initiated a concerted effort to improve the quality of the detector data, motivated in part by FHWA recommendations to provide travel times to the public rather than continually displaying "dark" DMS or posting generic messages such as "drive safely." Also, VDOT has begun to look seriously at performance measurement statewide. As a result, the data now being collected is vastly improved and several unreliable detectors have been identified for decommissioning.

In addition to the travel time initiative, VDOT, like many other DOTs across the country, has begun to put renewed emphasis on system performance measurement. Additionally, a public web page called the "Dashboard" (http://dashboard3 [internal] or http://dashboard.virginiadot.org [public]) now provides quantitative assessments of various aspects of the Department's performance, including congestion at various interstate locations. HOV travel speed performance, and travel times on key commuter routes. A screenshot of the dashboard is depicted in **Figure 3**.

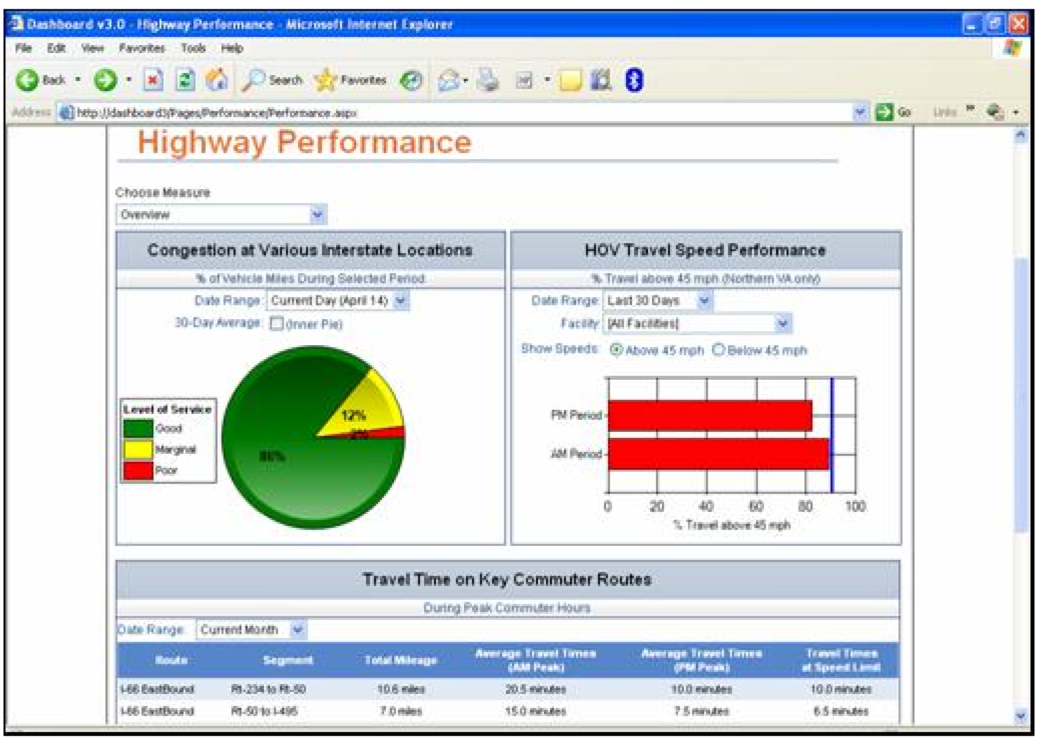

Figure 3. Dashboard Screenshot

In addition to the Dashboard, VDOT NRO is working with Virginia Polytechnic Institute (Virginia Tech) to develop a Real-Time Freeway Performance Monitoring System (RTFPMS). The purpose of this project is to develop a system that will assist the Northern Region TMC engineers and operators to identify, measure, and report the status of the freeway system and individual facilities. It is intended to give the user the ability to visualize data at many temporal and spatial scales. Additionally, this system will add value to the real time data by performing data aggregation and comparisons to historic or expected values. The outcome of this effort will be a web-based software tool system for use by TMC operators and freeway engineers for real-time and off-line analysis.

3.2 Stakeholders and their Roles and Responsibilities

The stakeholders for detectors and their various roles and responsibilities as they pertain to detection are presented in this section.

- **VDOT NRO TMC Operators**
  TMC Operators are the real-time operations staff at the NOVA Traffic Management Center, which is primarily responsible for monitoring traffic and responding to incidents. There are currently two types of operators: two call taker positions and three operators who monitor freeways—one for each of I-66, I-95/395 and I-495. In the future, the dedicated call taker positions will be converted to additional TMC operators. Within the TMC speed, volume, and occupancy data are used to identify locations of potential incidents or recurring congestion.

- **VDOT NRO Freeway Engineers**
  VDOT's Freeway Engineers are responsible for evaluating freeway operations performance and setting policy with respect to traffic management. This role has the largest need for traffic flow data from detectors, which may be used to help determine hours for HOV lanes and shoulder lanes, setting ramp metering policies, performance measurement, etc.

- **VDOT NRO Traffic Signal Operation Engineers**
  The Traffic Signal Operations staff is responsible for the development and maintenance of traffic signal timings plans for more than 1000 intersections in VDOT's Northern Region, which is the area shown in Figure 2 exclusive of Arlington County and the cities of Alexandria, Fairfax, Falls Church and Herndon. This role is primarily concerned with the creation of pre-timed signal timing plans and answering citizens' questions and requests. However, this group has the sole authority to change the selected timing plan on a VDOT maintained corridor in real-time.

- **VDOT Continuous Count Program**
  The Continuous Count Program (CCP) is responsible for collecting average daily traffic volume by vehicle classification from more than 400 continuous count stations across the state, 75 of which are in the Northern Region. This traffic data is used for many different applications from transportation planning to federal reporting under the Highway Performance Monitoring System (HPMS) program. CCP staff members perform thorough data quality checks daily to ensure detector integrity because accurate annual count data cannot have any time gaps.

- **VDOT NRO Maintenance**

The Maintenance Division is responsible for the maintenance and repair of all field devices, includes overseeing VDOT maintenance staff or administering maintenance contracts.

- **VDOT NRO Traffic Engineering**
  VDOT's Traffic Engineering group is responsible for ensuring safe, economical, and efficient traffic movement on roads, streets, and highways, their networks, terminals, and abutting lands. It uses detector data for studies related to traffic and safety, signal warrants, and signage.

- **VDOT NoVA, Fredericksburg, and Culpeper District Transportation Planning**
  Transportation Planning includes the analysis of vehicle, bicycle, and pedestrian traffic and is responsible for forecasting transportation needs and conducting transportation studies.

- **Regional Integrated Transportation Information System**
  The University of Maryland's Center for Advanced Transportation Technology (CATT) Laboratory has taken the lead in developing a system to help improve the transportation efficiency, safety, and security through the integration of existing transportation management systems. This system, the Regional Integrated Transportation Information System (RITIS), will enable the Metropolitan Washington D.C. The Metropolitan Washington, D.C. region to share transportation related information.

- **Private Sector**
  There are several private sector entities with a stake in VDOT's detection system. These entities mainly take and incorporate VDOT's detector data within their own value-added products and services. In some cases, these firms contribute their value-added components for VDOT's use, though with restrictions in many cases. In most cases, these products and services are centered on travel times or speeds for traveler information applications. Their key needs are for highly accurate and available data; specific locations of VDOT sensors are of less importance since they supplement with their own where needed.

- **Regional Media Outlets**
  Similarly to the Private Sector group described above, Regional Media Outlets draw upon VDOT's traffic information—whether incident information, camera images or traffic flow information—to provide traffic reports via radio or television. These are mainly local stations though there are nationwide companies that apply a similar business model to multiple regional markets, such as XM Radio.

- **Program Managers**
  Program Managers are mainly concerned with high level performance against goals and objectives. They need high quality traffic data that is aggregated and presented in a way that is meaningful and understandable for policy making. Both VDOT Central Office and NRO Planning and Business Administration have an interest in performance measures, the former with high-level metrics such as what is included in the Dashboard, the latter with measures that can be incorporated into strategic planning and target setting.

4 Operational Needs

The business needs for detection for the aforementioned stakeholder groups are defined in this section. Each group has its own specific needs, though different groups may have the same or similar needs. The needs listed here are intended to express the underlying objective of the stakeholder group in terms of what that group is trying to accomplish as it relates to the detector infrastructure. For most user groups, that need is focused on the data needs that can be met by detectors. However, the maintenance needs are focused on the characteristics of the detector devices themselves as they pertain to maintainability.

The needs documented here are deliberately high-level and focus on outcomes rather than methods. In a follow-up document, these needs will be given unique identifiers and high-level requirements of VDOT's detection system will be derived from the user needs. As stated previously, the needs are user-centric while the high-level requirements will be focused on how the detection system needs to be designed to meet those needs.

Needs for detector data can be categorized into real-time operations and off-line data analysis. Often, this is the same data but there are additional considerations for real-time data. In particular, real-time data has higher standards for accuracy and availability because it is relied upon by users on a continuous basis.

4.1 VDOT NRO Traffic Management Center Operators

4.1.1 Monitor Congestion Levels

TMC Operators need to be able to quickly identify anomalies in traffic patterns on freeways and key arterials in order to: (1) detect and respond to incidents and (2) provide accurate and timely traveler information to the general public.

4.1.2 Integrated Corridor Management

TMC Operators need to be able to quickly identify anomalies in freeway traffic patterns to manage capacity across multiple transportation modes (freeways, arterials, rail, bus, etc.).

4.1.3 Improve Operator Efficiency

TMC Operators need more automated tools to make them more efficient so they may monitor more miles of freeway than they are currently able.

4.1.4 Operate Ramp Meters

TMC Operators need real time traffic flow data to determine when to turn ramp meters on and off and when to override pre-set metering rates in real-time.

4.1.5 Ramp Meter Queue Alerts

TMC Operators need a reliable means of being alerted when ramp queue extends onto arterials so that metering rates can be adjusted in real-time to accommodate traffic conditions.

4.1.6 Operate HOV Facilities

TMC Operators need to be able to determine when to override regular HOV hours and open HOV lanes to all traffic during major incidents or emergencies.

4.1.7 Operate Reversible Flow Facilities
TMC Operators need to be able to determine when to reverse the direction of flow on reversible flow facilities.

4.1.8 Wrong-Way Traffic Alerts
TMC Operators need to be alerted of wrong-way traffic in reversible lanes.

4.1.9 Operate Controlled (Shoulder) Lanes
TMC Operators need to determine when to open controlled lanes to traffic.

4.1.10 Provide Travel Times
TMC Operators need to be able to show real-time travel times between certain points of interest on DMS message boards, 511, and other dissemination tools in order to alert travelers of traffic delays.

4.1.11 Actively Manage Speed Limits
TMC Operators need an automated system that will actively lower speed limits in response to real-time traffic conditions to alleviate and delay congestion along freeways.

4.1.12 Provide Queue Warning
TMC Operators need to be able to monitor the effectiveness of an automated system that will warn drivers of stopped vehicles ahead.

4.1.13 Manage Parking
TMC Operators need to display occupancy information for park and ride lots to alert drivers as to whether the lot is full.

4.1.14 Monitor/Facilitate Evacuation
TMC Operators need to be able to monitor traffic conditions and respond to incidents on all evacuation corridors during an evacuation.

4.1.15 Provide Traveler Information
TMC Operators need to inform travelers of current traffic levels with particular attention to how they deviate from what is normal.

4.2 VDOT NRO Freeway Engineers

4.2.1 Plan for Maintenance or Construction
TMC Supervisors need to use historical traffic data to set allowable hours for scheduled maintenance or construction.

4.2.2 Manage Major Roadwork
TMC Supervisors need to evaluate construction's impact on traffic.

4.2.3 Evaluate Effectiveness of Traffic Control
Freeway Engineers need to evaluate the effectiveness of traffic management and incident management strategies.

4.2.4 Evaluating HOV Lanes Hours of Operation

Freeway Engineers need to evaluate HOV lane usage in order to set policy with respect to when the HOV lanes should be in effect.

4.2.5 Evaluating Controlled (Shoulder) Lanes Hours of Operation

Freeway Engineers need to evaluate controlled lane usage in order to set policy with respect to when controlled lanes should be open to traffic.

4.2.6 Measure HOV Throughput

Freeway Engineers need to measure HOV person-throughput between each interchange.

4.2.7 Measure HOV Speeds versus General Purpose (GP) Speeds

Freeway Engineers need to measure and report on the differences in speed in HOV lanes and GP lanes between each interchange.

4.2.8 Evaluate Reversible Lane Operations

Freeway Engineers need to determine when to reverse the direction of flow on reversible lanes based on historical traffic patterns. This may be of particular interest on weekends, where the dominant direction of flow may be less predictable than on weekdays.

4.2.9 Monitor Ramp Meter Operations

Freeway Engineers need to set policy with respect to ramp metering rates and control modes (e.g., traffic-responsive vs. time-of-day).

4.2.10 Measure Ramp Volumes

Freeway Engineers need to measure ramp volumes for analysis and potential policy changes to metering rates.

4.2.11 Detect Mainline Traffic Flows

Freeway Engineers need to detect mainline traffic flows to adjust standard metering rates.

4.2.12 Queue Alerts

Freeway Engineers need to assess where, when, and how often ramp meter queues spillback onto arterial streets.

4.2.13 Evaluate Effects of Road Work

Freeway Engineers need to evaluate construction's impacts to traffic.

4.2.14 Monitor Lane Control

Freeway Engineers need to set policy with respect to when the controlled (shoulder) lanes should be open to traffic.

4.3 VDOT NRO Traffic Signal Operations Engineers

4.3.1 Integrated Corridor Management

Traffic Signal Operations Engineers need to be able to quickly identify anomalies in arterial traffic patterns to manage capacity across multiple transportation modes (freeways, arterials, rail, bus, etc.).

4.3.2 Detect Volumes in Real-Time

Traffic Signal Operations Engineers need to detect volumes on arterials (15 minute intervals) to evaluate whether to switch timing plans in real-time.

4.3.3 Monitor Turning Movements

Traffic Signal Operations Engineers need to monitor key turning movements on detour routes in real-time.

4.3.4 Optimize Signal Phasing and Timing

Traffic Signal Operations Engineers need to be able to use archive data to optimize the signal timing plan for a corridor.

4.4 VDOT Continuous Count Program

4.4.1 Collect Complete Data

The Continuous Count Program needs to be able to collect continuous traffic volume data between each freeway interchange.

4.4.2 Collect Reliable Data

The Continuous Count Program needs to be able to detect within a day whether any detector is malfunctioning.

4.4.3 Collect Data Daily

The Continuous Count Program needs to be able to collect daily data for no greater than 15 minute time intervals.

4.4.4 Vehicle Classification

The Continuous Count Program needs to collect vehicle classification data in accordance with FHWA categories at a sample of locations.

4.5 VDOT NRO Maintenance Division

4.5.1 Minimize Maintenance Work Orders

The maintenance division needs to receive as few work orders as possible, which is aided by maintainable design, regular inspection, preventative maintenance and appropriate life cycle replacement of equipment that has reached its usable life.

4.5.2 Troubleshoot Detector Problems Remotely

The maintenance division needs the ability to troubleshoot and solve simple maintenance problems remotely to reduce trips to the field.

4.5.3 Perform Routine Maintenance and Repairs Quickly

The maintenance division needs to be able to perform routine maintenance and repairs quickly when trips to the field are necessary.

4.5.4 Safe Conditions

The maintenance division needs safe conditions for technicians maintaining devices in the field.

4.5.5 Inventory / Lifecycle Replacement

The maintenance division needs to develop and continuously update a formal detector inventory and lifecycle management system according to Appendix B.

4.6 VDOT NRO Traffic Engineering

The needs for Traffic Engineering staff are largely those already listed under Freeway Engineers. Additional needs for Traffic Engineering staff are for spot studies for safety, signal warrants, etc. However, these studies do not require continuous data collection and by their nature, their locations are unpredictable.

4.7 VDOT NoVA, Fredericksburg, and Culpeper District Transportation Planning

4.7.1 Perform Accurate Forecasting

Transportation Planning needs high quality historic and current traffic flow data to ensure that it has accurate forecasting with which to set in place future policies and planning, particularly at county boundaries.

4.7.2 Collect Origin/Destination Data

Transportation Planning needs high quality origin and destination trip data to ensure that it has accurate forecasting with which to set in place future policies and planning.

4.7.3 Study Validation

Transportation Planning needs high quality historic and current traffic flow data to verify that its studies are accurate in order to reinforce its decisions regarding policies and planning.

4.7.4 Monitor Park and Ride Lots

Transportation Planning needs to know whether and how often a lot is full to be able to determine if additional lots are needed and where they should be located.

4.8 Private Sector

The private sector needs high quality and high availability speed data to provide traveler information.

4.9 Program Managers

Program Managers need access to performance measures for use in strategically managing investments.

4.10 Regional Media Outlets

Regional Media Outlets need to disseminate accurate incident and traffic information to the traveling public.

5 System Overview

This section presents an overview of the system to be developed and the key considerations for its design. The system in this case is a collection of one or more applications using detectors that will deployed on a corridor-by-corridor basis over time. Therefore, this section will discuss key considerations as they relate to different applications and locations, where appropriate. These applications include, but are not limited to, HOV operations, reversible HOV operations, ramp metering, lane control, travel times, performance measures.

5.1 Relationship with Other Systems

Detectors are related to many other systems as there are many different current and future applications that require traffic data.

- **DMS.** Detector data will be used to post messages on DMS such as travel times, queue alerts and variable speed limits.

- **Gate Control/Reversible Lane System.** In a real-time environment, detectors can be used to detect wrong way traffic. In an off-line environment, they can be used to determine optimal hours for the operation of reversible lanes, particularly on weekends when travel patterns are less predictable and more dependent on special events, holidays and other factors. Detectors can also be used to determine the performance and utilization of the reversible HOV lanes.

- **Lane Control System.** In real-time, detectors can be used to determine when shoulder lanes should be open to all traffic in case of greater-than-normal congestion. Off-line, detection can be used to set policy for when controlled lanes should be open to all traffic.

- **Ramp Metering System.** Detectors can be used for traffic-responsive ramp metering, to set time-of-day metering rates, and to detect queue spillback onto side streets.

- **Traffic Signal System.** Detectors are used for real-time signal operations and to generate historical volumes for signal timing. For this Concept of Operations, the focus is on how detectors can be used to prompt engineers to enact incident response timing plans, arterial traveler information and arterial performance measures.

- **Active Traffic Management (Future).** This includes applications such as variable speed limits (VSL), mainline queue detection and warning systems, and ramp metering. While only ramp metering is being used currently, VDOT has plans to implement other active traffic management technologies in the near future. These will require detectors to be located appropriately and capture the appropriate traffic flow data.

- **Vehicle-Infrastructure Integration (Future)**. While VII is still in the research and development stage, it is emblematic of a recent shift in emphasis in the industry from infrastructure-based to probe-based traffic detection. Though it anticipates this will not be a reality before the end of life is reached for any detectors deployed today, any long-term plans for traffic detection should consider the role VII could potentially play.

5.2 Summary of Device Locations

Due to the nature of this effort, the specific locations of future detectors are not determined as part of this Concept of Operations. Rather, they will be derived from high-level requirements detailing the detector needs for different applications combined with a detector master plan that defines priority corridors for where these applications will be implemented as opportunity arises.

The following definitions are used in this document to describe the level of spatial resolution on detector data. They are shown graphically in **Figure 4**. A similar model can be used for arterial streets with the exception that a Link need not be homogenous. Rather, it is synonymous with a Section—the length between successive intersections.

- **Zone (or lane-by-lane):** Represents the actual spot zone of coverage, e.g. lane.
- **Station:** Represents the aggregation of all equivalent lanes with the same function and same direction, i.e., HOV and GP lane groups at a location would be different stations.
- **Link:** Links are defined as sections of contiguous road with the same cross section, lane use type and merging/weaving behavior. For example, approaching an interchange, a link would be defined as the distance from the beginning of the deceleration or exit lane to the end of the acceleration lane or on ramp. At the end of the acceleration lane a new link would start.
- **Section:** A collection of contiguous links, such as between major interchanges.
- **Freeway:** A collection of contiguous sections.

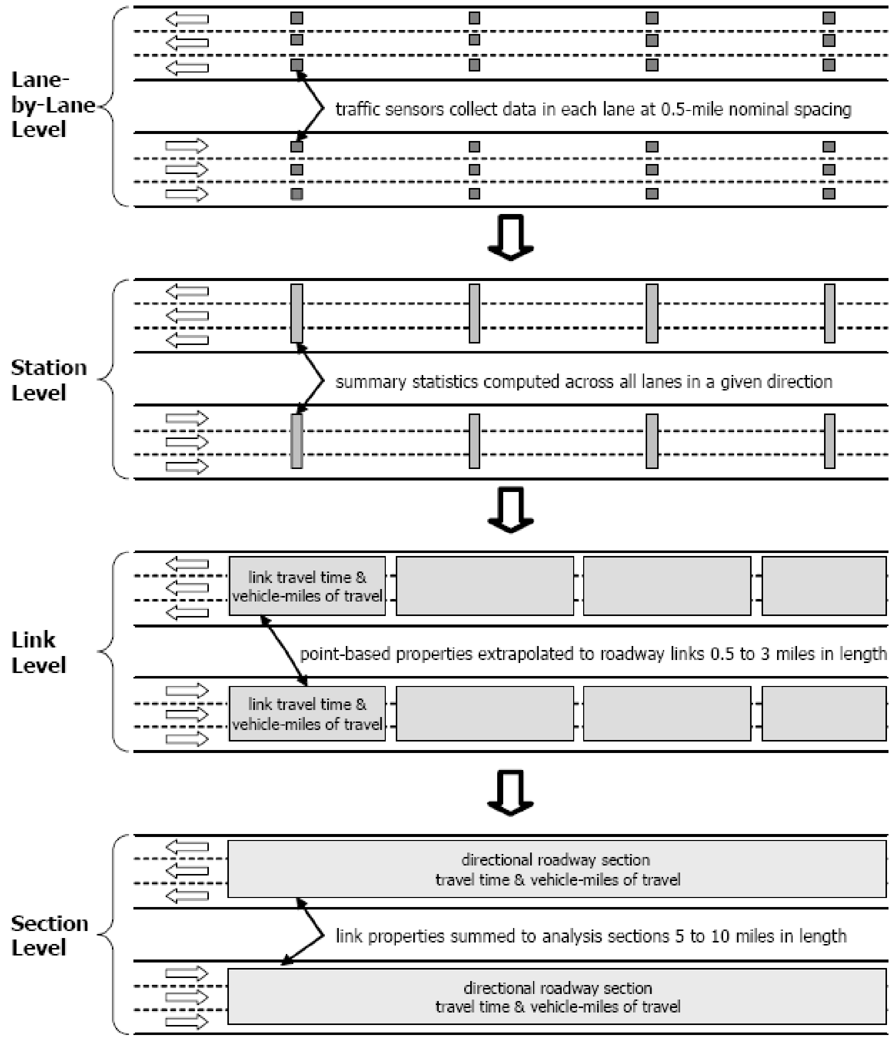

Figure 4. Aggregating Traffic Detector Data to Different Geographic Sites

(Source: Turner, S.R., Margiotta, T., Lomax. Monitoring Urban Freeways in 2003. Current Conditions and Trends from Archived Operations Data. Report No. FHWA-HOP-05-018, Accessed at http://mobility.tamu.edu/mmp/FHWA-HOP-05-018/ , December 2004

5.3 Communication Requirements

The majority of existing detectors communicate via contact closures that connect to 170 controllers in field cabinets. All loops communicate this way, as do some radar detectors. The 170 controllers aggregate the detector data into 20-second time slices prior to transmittal to the TMC over the agency-owned fiber optic network. Newer radar detectors can aggregate data internally and communicate directly to the TMC on fiber, without passing through a controller. While the current fiber optic communications network is a pair of SONET folded rings, a migration to an IP network is underway. Its expected the new network will simplify the integration of new field devices and provide additional bandwidth.

As a low bandwidth device, detectors also have the option of communicating via cellular modems where there is no existing communications infrastructure, although it does incur a nominal monthly cost.

5.4 Software Requirements

All of the needs listed in Section 4 involve detector data, but many also require some amount of post-processing for display, aggregation, fusion or report generation. While features such as congestion maps are standard features of ATMS software, other features may not be. These include the calculation of travel times from point and/or probe sources, alerting operators of queue spillback at metered ramps, and accurately identifying traffic patterns that deviate from a typical profile and alerting operators in a way that is helpful and improves rather than degrades their efficiency.

In the presentation of high-level requirements that map from the user needs in this Concept of Operations, specific software requirements will be identified. Those that are not already met by VDOT's newly procured ATMS software will be highlighted.

5.5 Project Architecture

This Concept of Operations will lead to a prioritization of detector deployments, which will lead to the identification of future implementation projects. Project architectures will be defined for these projects as they are conceived.

In general, however, in the VDOT NRO Regional ITS Architecture detectors are a part of the inventory element, VDOT NoVA STC Field Equipment (Note since the architecture was last updated, VDOT's Smart Traffic Centers have been renamed Traffic Management Centers (TMCs)). **Figure 5** shows the interconnect diagram from the Regional ITS Architecture associated with this inventory element. Note that an update to the architecture is planned to reflect the reorganization of VDOT's ITS program from districts to operations regions.

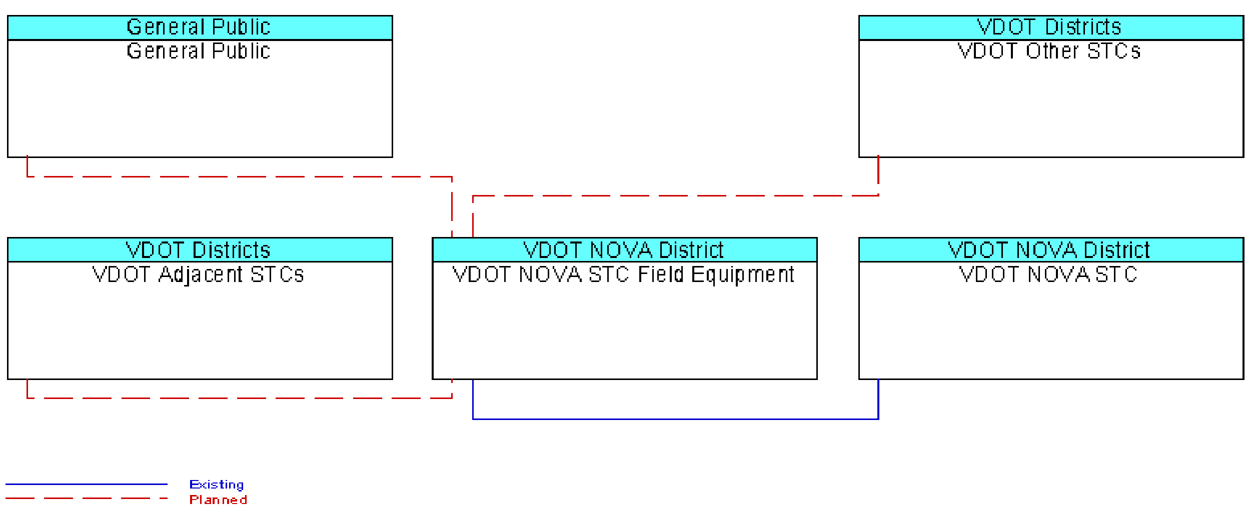

Figure 5. VDOT NOVA STC Field Equipment Interconnect Diagram

The following National ITS Architecture Market Packages are associated with VDOT NOVA STC Field Equipment:

- ATIS09 - In Vehicle Signing
- ATMS01 - Network Surveillance
- ATMS02 - Probe Surveillance
- ATMS04 - Freeway Control
- ATMS05 - HOV Lane Management
- ATMS06 - Traffic Information Dissemination
- ATMS08 - Traffic Incident Management System
- ATMS18 - Reversible Lane Management
- ATMS19 - Speed Monitoring
- ATMS20 - Drawbridge Management
- ATMS21 - Roadway Closure Management

The following National ITS Architecture Functional Areas are associated with VDOT NOVA STC Field Equipment (all of these relate to, or make use of, detection in some way):

- **Field Barrier System Control -** Field elements that control barrier systems such as gates and other systems that manage entry to roadways, transportation facilities and infrastructure.
- **Roadway Basic Surveillance -** Field elements that monitor traffic conditions using loop detectors and CCTV cameras.
- **Roadway Freeway Control -** Freeway control equipment including ramp meters, mainline metering, and lane control equipment which controls traffic on freeways, including indicators to drivers.
- **Roadway HOV Control -** HOV lane usage traffic sensors and display equipment to notify users of HOV lane status for control of traffic in HOV lanes on freeways.
- **Roadway Incident Detection -** Field elements that provide video images of traffic conditions, including advanced CCTV cameras with built-in incident detection algorithms.
- **Roadway Probe Beacons -** Field elements to collect traffic and road conditions from passing vehicles; both anonymous toll/parking tag readings for link time calculations and smart probe data supported.
- **Roadway Reversible Lanes -** Traffic sensors, surveillance, and automated reversible lane equipment and lane control signals to control traffic in reversible lanes.
- **Roadway Speed Monitoring -** Vehicle speed sensors that detect excessive vehicle speeds, informing drivers, centers and/or enforcement agencies of speed violations.
- **Roadway Traffic Information Dissemination -** Driver information systems, such as dynamic message signs and Highway Advisory Radio (HAR).

5.6 Other Projects that may Affect, Enhance, or Provide Opportunities

5.6.1 HOT Lanes

It is estimated that over $5 billion of construction projects will be initiated on Northern Virginia highways within the next few years. The largest shares of that are the planned HOT lanes projects on I-495 and I-95/395. These projects will be funded, built and operated by a private tolling company. On I-495, which is further along in the design phase, new lanes will be added that will have toll rates that vary based on real-time demand to ensure congestion-free travel. Plans for I-95/395 are less certain, but it is likely the existing reversible lanes will be converted to toll lanes and extended southward.

The implications for detection on HOT lanes corridors are many. For I-495, plans are for the private firm to install and maintain detectors at 1/3-mile spacing on both the HOT lanes and general purpose (GP) lanes. Plans for I-95/395 are less certain, but given the similar nature of these projects and that they are being designed an operated by the same firm, it is reasonable to assume the plans for spacing and maintenance will be the same.

5.6.2 Private Sector Providers of Traffic Flow Data

In Northern Virginia, there are several firms competing to sell traffic data to VDOT. These include SpeedInfo, Traffic.com, Airsage, Delcan and Inrix. While there may be others, these are the predominant players. Each of these firms presents different technologies, approaches and business plans to acquire, package and resell traffic data. The offerings of these firms, in terms of available data, data quality, and terms and conditions for use of that data, will present VDOT with a number of alternatives to deploying detection on its own. While much could be written about the various business models of these firms, this section gives a quick summary of the pros and cons of private sector traffic data and the various firms' data offerings.

There are pros and cons to relying on private sector providers for traffic data. The benefits include a reduced maintenance burden and a contractually guaranteed level of data quality and availability. In addition, costs may be lower for providers with greater economies of scale, i.e., those with other customers that can help distribute the private firm's deployment and maintenance costs. Some of these providers can also provide value beyond what is available to VDOT, namely contracts with fleets or cell phone carriers that are used to obtain probe traffic data from these sources. Private sector data can be used to supplement the agency-owned deployment for infill or expansion, and it is generally a low-risk proposition with a low initial investment and the ability to cancel the contract if it proves unsuccessful.

There are downsides to the reliance on private sector data as well. Private sector traffic data providers often rely on agency-owned detection as a primary source to supplement their own. Therefore, without continued investment by VDOT, it is unclear how accurate or reliable this private sector data may be. Also, some of these firms relying on alternative sources, i.e., fleets or cell phones, do not disclose the probe vehicle market penetration, nor the extent to which they rely on agency-owned detectors or historical data. For these unknown data sources, which are assumed to include trucking and delivery fleets, it is unclear what their travel patterns are, i.e., whether they avoid peak periods and to what extent they travel on arterial roads where probe data would be most desirable. Therefore, while the data may exhibit characteristics of highly accurate data (following expected day of week and peak period trends), it is unclear without testing how accurate the data actually is. Given the newness of some of the alternative sources of data in the U.S. and the unknown market penetration, this presents a level of risk. For private firms deploying their own point detection, there are often limits to how these data can be used for traveler information by public agencies. The business models for these firms have not proven themselves, in large part because of this conflict with their public agency partners—from whom they rely on for core detection in urban areas—and because the revenues have generally not been realized that will offset the relatively high cost of traditional point detection.

- **SpeedInfo** – SpeedInfo has developed a low-cost Doppler radar detector that runs solely on solar power and communicates via cellular modem with the companies servers in California where it aggregates the data. The sensor does not measure traffic continuously, nor does it differentiate between lanes, which makes it unsuitable for some applications.

- **Traffic.com** – Traffic.com has already deployed approximately 30 radar detectors on I-495 and the Dulles Toll Road in Northern Virginia. These detectors continuously measure lane-by-lane speed, volume and occupancy, making them suitable for most applications. There are contractual terms currently in place limiting how VDOT may use the data. Most notably, VDOT may not use Traffic.com's detector data to provide travel times on DMS. New contract terms are being developed in the coming months, however, that may remove this restriction. Given that new detectors are being installed for the HOT lanes project on I-495, Traffic.com will likely move its detectors to other routes.

- **Airsage** – Airsage's business model is to extract and package traffic flow data from cellular phone carriers. Given the high market penetration of cell phones (past studies have estimated that more than half of all vehicles have a cell phone in them that is turned on—a necessary prerequisite for determining its location), and the GPS capabilities of the newest models, this could potentially be a ripe source for traffic probe data. To date, however, it has not proven to be accurate. A recent study conducted by UVA focused on Northern Virginia showed average travel time estimation *errors* in the range of 70%.

- **Delcan** – Delcan, in cooperation with UK firm ITIS Holdings is conducting a pilot of probe vehicle fleet data collection in Baltimore City.

- **Inrix** – Inrix recently was selected for a contract to provide probe-based traffic data to members of the I-95 Corridor Coalition, which VDOT is eligible to tap into. Inrix contracts with fleets that monitor their individual vehicles with GPS technologies. Using this, combined with other data as available—including public sector point data—Inrix estimates travel times. While VDOT has access to the terms and conditions and cost schedule from the I-95 contract, Inrix holds closely to its data sources, algorithms and methods for fusing disparate data. As a result, data quality must be determined through ground truth data collection.

5.6.3 New ATMS Software

Though mentioned above under Section 5.4, VDOT NRO's recent selection of a contractor to provide new ATMS software for its TMC is an important factor in future plans for ITS in the region. The current software has exceeded its useful life and the knowledge that it will soon be replaced has discouraged any modifications to support new technologies. The new software will provide a platform for new development of new applications such as active traffic management, travel times, and performance measurement.

5.6.4 IP Communications Upgrade

VDOT NRO is upgrading to an IP-based 10 Gigabit Ethernet (10GigE) backbone for ITS field communications along I-95/395 and I-66 with a physical ring connection along Route 234. This upgrade is expected to be completed by the end of 2008. Native IP detectors along these routes will be able to access this network directly through a field Ethernet switch. In addition, the IP architecture will also allow remote detectors using cellular modems to access the IP network directly without passing through a field controller.

5.7 Constructability Considerations

To a small extent, constructability considerations have been addressed in terms of the needs of the maintenance division in Section 4. More details will be given in the detector requirements that relate to maintainability.

6 Operational and Support Environment

This document identifies the need for several new applications for detectors, many of which require additional man-hours of effort, new hardware and/or software, and new operating procedures. This section addresses each of these operational support areas.

6.1 Personnel

For the real-time applications, TMC Operators may have additional responsibilities. For instance, applying traffic-responsive ramp metering will require additional monitoring to ensure the system is functioning properly. However, at the same time, an improved congestion map and more reliable detection of anomalies in traffic patterns could reduce operator load and offset these additional responsibilities. In addition, the new ATMS software should be able to automate many of the procedures that are currently performed manually. This will need to be evaluated on an ongoing basis.

VDOT should consider whether a new operator position should be identified—one with specialized expertise in active traffic management. Or, depending on workload, VDOT should provide specialized training for TMC Operations Supervisors should traffic-responsive metering or other active traffic management applications be employed.

VDOT should also consider a new position or an ongoing contract with a university for data reduction and analysis for performance measurement. In order to take the raw data from the TMC and translate it into meaningful information that can be used to truly assess VDOT's operational performance, regular effort is required. This can never be truly automated because it requires different data sets to be merged, e.g., traffic data and incident reports. Further, the relative contribution of incidents to congestion requires some judgment from an inspection of the data. However, this is a vitally important measure because it reflects on how well VDOT is responding to incidents and helping to manage them.

6.2 Facilities

No new facilities are envisioned for future detector expansion and upgrades.

6.3 Hardware and Software

All new functionality can be integrated with NRO's new ATMS software. Depending on the complexity of the desired application, a short or lengthy period of development and testing will be required.

6.4 Operating Procedures

Operating procedures would need to be revised for the following sections of the Northern Virginia Smart Traffic Center Standard Operating Procedures document.

- **Reversible Lane Operations (7.4.4)** – Procedures would need to be written to define the criteria under which reversible lanes should be reversed, based on an analysis of historical traffic patterns.

- **Ramp Meter Operations (7.4.5)** – Instead of detecting queue spillback onto adjacent arterials through "CCTV or citizen calls," the detection system would notify the operator and/or modify the metering rate automatically. In addition, operators would need to be able to modify ramp metering hours in response to congestion, or monitor a traffic-responsive system that makes such decisions automatically.

- **DMS (7.4.6)** – Operators will be introduced to a new system where messages will have priorities and each DMS will have a message queue at any given time. Travel time messages will have a lower priority than incident-related messages, for instance. Operators will need to be able to assign priorities to messages relative to the base travel time message.

New operating procedures would be needed for new applications such as variable speed limits, mainline queue detection, park and ride occupancy monitoring, and warning systems.

6.5 Maintenance

Maintenance will be conducted as for all other field devices. Opportunities to effectively apply capital dollars to maintenance in the form of purchasing data from the private sector should be considered whenever evaluating the relative merits of agency-owned infrastructure compared with outsourcing.

A key consideration for maintenance is tracking inventory, particularly to ensure availability of spares. For this purpose, NRO is planning to implement a barcode tracking system for its Inventory and Maintenance Management System (IMMS). The barcode requirements for detectors and other devices are given in Appendix B.

When deploying system detectors throughout the region, a percentage of the capital construction project should be effectively added to the annual maintenance funding in support of the personnel and equipment needed to maintain an expanded system. A common rule of thumb is that maintenance will cost 10% of the one-time capital cost annually. A typical cost for a detection station is $25,000 per site assuming available power and communications. The annual maintenance cost would then be approximately $2,500 per year. It must be noted, however, that this depends on the maintainability of the design, remote troubleshooting and reset capabilities of the device. If fiber or other fixed line communications is not available, cellular communications is available at an approximately monthly recurring cost of $75 or $900 per year.

7 Operational Scenarios

This section describes seven operational scenarios that detail how implementing various applications for detectors would function. The scenarios are designed to bring to light any requirements for the detection system that would otherwise be overlooked in the needs gathering stage. These scenarios are not meant to be exhaustive, but rather to highlight those deemed to have the most impact on the proposed detector deployment and operating procedures.

7.1 Freeway Traffic Management (Non-incident) Scenario

A TMC Operator is monitoring traffic on a typical day. The Operator has various visual aids to assist him in assessing the condition of traffic over his area of responsibility. These include a map that displays current congestion levels over the area compared with what is typical so that a visual inspection can help the Operator to identify any anomalies requiring special attention. On this particular day, however, there is an event in Arlington that was not foreseen to have a major impact on traffic. However, there is unusually heavy mid-day traffic on I-66.

The Operator is alerted to the abnormal traffic patterns on I-66 through his visual display and seeks approval to turn on ramp meters to alleviate bottlenecks. The supervisor grants that permission and the traffic-responsive program sets the appropriate metering rates. The Operator is alerted to ramp spillback at one particularly short ramp, manually flushes the ramp, and resumes the traffic-responsive program at that ramp. A record is logged that spillback occurred at that ramp, along with the time of day, the traffic-responsive program being run, and the ramp volumes along the corridor for later trend analysis. If this ramp or traffic-responsive program becomes a recurring problem, the traffic-responsive program will be modified appropriately.

The Operator consults with the Supervisor to determine whether shoulder lanes should be open to traffic during this mid-day period. Based on the volumes heading outbound from Arlington, it is determined that exiting general purpose lanes outside the Beltway should be able to handle the influx of traffic and no change is made.

7.2 Freeway Incident Management Scenario

A TMC Operator is monitoring traffic on a typical day. The Operator is alerted via his ATMS workstation of an accident on inbound I-66 at the start of the morning peak period. In addition to his other responsibilities for tracking the status of the incident for traveler information purposes, he also monitors ramp metering rates to ensure they are responding to changes in traffic patterns. Using the congestion map to locate the back of the queue using speed or occupancy data, the Operator populates the appropriate DMS to alert drivers of stopped traffic X miles ahead, a message that alternates with the default travel time message. Effects of the incident have propagated upstream to segments with HOV lanes. In consultation with the Operations Supervisor, the

Operator determines whether HOV lanes should be open to traffic to allow Beltway traffic to exit more easily. In addition, TMC Operators, in consultation with Operations Supervisors, alert Signal Timing Engineers of bailout traffic on key exit ramps and provide estimates of the additional traffic on the alternate route using real-time ramp volume data compared with typical counts. Signal Timing Engineers use this information to determine whether a different timing plan would be appropriate during the incident condition.

7.3 Recurring Bottleneck Scenario

Westbound traffic volume on I-66 west of Gainesville is rapidly increasing at the start of the afternoon peak period. At the bottleneck caused by the lane drop, traffic demand begins to approach capacity. Based on algorithms calibrated from historical traffic demand patterns, upstream DMS reduce speed limits for traffic approaching the bottleneck. When demand begins to exceed capacity, approaching traffic is notified of the stopped traffic ahead. A TMC Operator monitors this system to ensure it is functioning as intended. If not, the Operator intervenes by manually changing messages and/or speed limits. This Operator action is logged by the system, along with the state of the system at the time of the intervention, for later trend analysis and performance assessment of the VSL and queue alert system.

7.4 Evaluate HOV lanes hours of operation

HOV lanes exist to encourage drivers to carpool during peak periods and to encourage those who cannot to drive during off-peak hours. It is important for VDOT to know what hours of the day HOV lanes are the most beneficial. Comparing per-lane volumes in HOV lanes vs. GP lanes, and assuming one occupant per vehicle for GP lanes and the minimum required number of occupants in HOV lanes, Freeway Engineers can quantify the effectiveness of the HOV lanes to move people compared with the GP lanes. It also gives a measure of how well the HOV lanes are being utilized at various times of day. Freeway Engineers can take archived traffic data and determine whether the HOV lanes are being fully utilized for the full HOV hours of operation. Freeway Engineers use this knowledge to help determine whether HOV hours of operation are appropriate, and make defensible and informed recommendations to decision makers.

7.5 Evaluate effectiveness of traffic control

It is important for Freeway Engineers to evaluate the effectiveness of traffic control strategies to help set operations policies. The Freeway Engineer, or someone under his supervision, accesses a database of quantitative traffic flow data and the causal factors of congestion such as incidents, weather, or construction lane closures. He performs a post-analysis of these events using traffic data to try and quantify the effects of the event. Using data on past similar events and historic typical traffic flow patterns, he assesses the effectiveness of the TMC Operations. For instance, an improved ATMS interface may allow TMC Operators to more rapidly detect incidents, more quickly and easily alert multiple third parties, provide richer descriptions of the incident, and update its status more frequently and in a timelier manner. Determining the entire effect of an incident, including its residual effects on traffic queues, can help Freeway Engineers to determine how effective Operators' tools can be. It can also determine the effectiveness of ramp metering strategies, integrated corridor management and active traffic management strategies. On a periodic basis, Freeway Engineers can determine performance relative to realistic benchmarks based on historical data.

7.6 Performance Measures Reports

Freeway Engineers and several other stakeholders within NRO and statewide, have a need to create performance measures reports describing the effectiveness of traffic operations during a previous time period such as the past month. For purposes of this scenario, we will assume the report creation is done by a university. Each month, university researchers access a database of the previous month's traffic flow, incident, weather and construction data. Using this data, they compare trends in congestion at different locations with previous months and attribute causal factors from incident, weather and construction data sets. All of this data is easily accessible from various real-time databases so a month's worth of data can be analyzed right away the next month. These reports use segment travel times as their primary basis for determining the performance of the freeway system, though they also consider volumes and HOV utilization to derive person-hours of delay, which can be monetized using an assumed time value of money. The share of any performance improvements that can be reasonably tied to operations performance (e.g., new SOPs, additional staff, streamlined tools, etc.) can be monetized for their benefit.

7.7 Failed Device Scenario

A detector is returning erratic data and is flagged by real-time data quality filters. A maintenance ticket is created on that detector describing the fault. VDOT's maintenance staff responds to the maintenance request by running remote diagnostics, which often enables them to reset the device and get it running again without having to go out to the field. In this case, however, that does not work and maintenance staff arrives in the field with replacement parts for the key components of the detector system that has failed. Before leaving for the field, they had configured the spare parts with the parameters in the failed unit. When they arrive, they pull their truck over to the shoulder or onto the grass, not needing to block lanes and set up maintenance of traffic. They quickly swap out the failed unit for the replacement, ensure it is collecting data properly, and return to the shop to diagnose the failed part. Once it is fixed or, if under warranty returned to the manufacturer, it is added to the stock of replacement parts.

8 Next Steps

The next steps are the development of high-level requirements from the needs identified in Section 4 of this Concept of Operations, the development of a validation plan to be used once the identified systems are in place, and a master plan for detection that prioritizes applications and corridors based on criteria such as ADT, crash rates, importance to the region, the ability to leverage existing investment.

The Concept of Operations for detectors presents new devices and operating procedures requiring integration into the new ATMS and daily operations of the system stakeholders. This section reviews areas of next steps within the systems engineering process to carry these operations concepts forward to the implementation stage.

8.1 Detailed Requirements

The VDOT NRO Systems Engineering group will develop detailed functional and performance requirements for detector data on the corridors identified in the detector master plan. Based on a market analysis of opportunities for private sector detector data, a determination will be made whether procure the required data through a performance-based specification or whether to deploy agency-owned infrastructure.

For agency-owned detection, the Systems Engineering group will develop requirements for all system components along with the specific siting of these components, including detectors and supporting equipment. Design requirements will cover a robust, dependable installation of field devices and requirements for operations and maintenance staff. More detailed requirements for incorporation into specification and procurement documents will be provided as part of system design.

Alternatives to deploying agency-owned detectors are to work with private sector firms who wish to deploy their sensors on VDOT's right-of-way or to procure data on a performance-based contract. The former would include firms like Traffic.com and SpeedInfo, who already have—or are planning—their own sensors on VDOT right-of-way. For these, the high-level requirements in Appendix A are sufficient and detailed requirements are not needed. The latter would include probe data providers such as Inrix, Cellint or Airsage. For these, the detailed requirements would not pertain to device siting, power, communications and other such specifications. Rather, they would need to rigorously define data quality, availability and other similar requirements for the data to be provided that is independent of the specific technology or means with which it is collected by the data provider.

8.2 System Design

For agency-owned detection, Systems Engineering will perform or oversee detailed design of integrated communications to the ITS elements and integration with existing VDOT TMC systems. This will include new detectors and related communications and power supply equipment. If creative approaches or unfamiliar equipment—such as non-tolling probe detectors—are incorporated into the design, prototype testing should be performed to minimize risk. System procurement(s) may occur as part of a design-bid build or as part of a design-build procurement; the approach will be determined by VDOT.

If the field equipment, communication system, or intended operations require changes to the ATMS, the designers will consult with the software vendor to identify the approach and minimize software development risk. They will prepare detailed specifications for the software work so that VDOT can arrange for that work to be performed.

8.3 Software/Hardware Development Field Installation

All field installation for detectors will be conducted by VDOT NRO Operations Installation & Construction (OIC) according to the specifications (detailed design or design-build, as approved by VDOT), and will be inspected by VDOT NRO OIC. OIC, however, may choose to use a contractor for either activity. All new equipment in the field will be asset tagged for tracking in the IMMS.

Meanwhile, VDOT's central software contractor will complete the necessary modifications of the ATMS. VDOT NRO ITS- Information Technology (IT) Section will oversee coordination between the CCTV contractor and the central software contractor. This may include providing samples of field equipment to the software contractor for use in testing the software during development.

8.4 Unit/Device Testing

This project will require testing geared toward data collection accuracy over one or multiple lanes, the ability to aggregate and transmit the data as specified, and the reliability of the communications. Factory acceptance testing will be required for each unit of certain materials, such as the detectors themselves. Some equipment may be tested after delivery but prior to installation, if that makes testing easier. For example, if cellular communications is being used in outlying areas, the signal strength and bandwidth using the supplied modem(s) may be tested prior to installation. All items will be inspected or tested after installation.

Prior to testing, the contractor will be required to provide proposed test procedures for VDOT NRO OIC and ITS-IT approval. For some items, the project specifications will describe some of the tests that must be performed. In addition, there will be a general requirement that all tests and diagnostic activities recommended by the equipment manufacturer must be performed. There will also be a general requirement that unit testing of items that are intended to communicate with the TMC must be tested while communicating with the TMC.

The project specifications will stipulate the relationship between the unit testing and payment. For most items, the contractor will receive a progress payment when the materials are delivered, and the remaining portion of the bid price (other than retainage) when the item passes its unit test. For items whose suitability cannot be completely determined by inspection upon delivery, no progress payment will be allowed. For items whose suitability cannot be completely determined based on unit testing, a portion of the bid price may be paid when the item passes its unit acceptance test, but the remainder will not be paid until the related subsystem and system tests have been passed.

8.5 Subsystem & System Verification and Acceptance

Once all devices and components are individually tested and accepted by VDOT NRO OIS & ITS-IT Sections, the contractor is responsible for testing of specific subsystems functionality to verify that they meet all pertinent operational and performance requirements as documented in the specifications. In most cases, the system or subsystem under test will include the central software, so testing may reveal problems that are the responsibility of the central software contractor, not the detector installation contractor. The project specifications must deal with this possibility, indicating how this eventuality will affect payment. VDOT NRO OIC and ITS-IT are to witness the testing and will either (a) develop a punch list of items or issues to be resolved, or (b), if there are no remaining items or issues to be resolved, authorize the start of the system acceptance test.

The system acceptance test, sometimes called a "burn-in" period, entails 30-days of normal operation with all systems in place. Completion of the acceptance test will assure that all systems are fundamentally operational. Any major failures which occur within the system operation during the 30-day period will cause the 30-day clock to start again, until such time that 30 days go by with the system in full operation. Any item that fails in large numbers will be replaced in its entirety.

8.6 System Validation

As part of the systems engineering process, a validation plan is typically completed to complement the Concept of Operations. This plan defines expectations so that when completed, all stakeholders can agree on whether the system designed or deployed met its objectives.

After a detection deployment project has been completed, during the first year of operation, VDOT will determine the extent to which this project meets its intended objectives based on the validation plan and the data collected in accordance with that plan. The validation may reveal opportunities to improve the procedures used to develop and implement similar projects in the future. It is provided in Appendix C. Developing the validation plan prior to project implementation enables relevant data to be collected before the project for use in before/after comparisons.

8.7 Operations & Maintenance

Detector system expansion will become increasingly more important for the NOVA TMC's traffic management processes. Disruptions or failures in the performance of these functions will adversely impact VDOT's ability to effectively manage traffic, improve operator efficiency and provide high quality traveler information, which will be particularly visible for travel times posted on DMS. The problem is further complicated by the fact that today's systems, subsystems, and components often are highly interdependent, meaning that a single malfunction can critically impact the ability of the overall systems to perform their intended functions.

VDOT NRO Maintenance will continue to own and maintain agency-owned detectors. However, operations and maintenance for detection equipment, as with other similar systems in the region, could be included in contracted maintenance, since most if not all the components are expected to be compatible with similar devices elsewhere in the Northern Region Operations area. Additionally, funding routine device maintenance and/or replacement should be included in annual budget reviews. The use of 10% of the initial capital investment cost is widely accepted industry practice. Outsourcing warranty and repair of these items will come at a higher premium, which will be dependent on the quantity and type of equipment to be maintained, and more importantly the response times.

In order to better define the high level requirements corresponding to the various user needs, it was helpful to create two distinct profiles, each with four subgroups to be used with specific applications. The first profile sets requirements for detectors used in real-time/operations data collection. This is mainly required by TMC Operators. The second profile sets requirements for detectors used in off-line operations analysis, predominantly used by Freeways Engineers. Each profile has the same set of subgroups. The first (subgroup A) relates to detectors used where the lane-by-lane data is required as well as speed, volume and occupancy. These requirements relate to locations with HOV lanes, controlled/shoulder lanes and ramp meters. The requirements in Subgroup B correspond to most other needs. These do not require lane-by-lane data, nor do they require and volume and occupancy. For these needs, speed and/or travel times are sufficient. The last subgroup, C, specifically applies to the requirements of detectors used in the application of ramp metering activities.

Each profile and subgroup is evaluated by seven criteria, specifying the high level requirements of the detectors in that profile and subgroup. The first criterion, Element, refers to what type of data must be collected. In all cases speed information is necessary, but volume and occupancy are only required for more detailed applications. The second criterion, Temporal Resolution, describes the amount of time data is bundled into for data collection and analysis purposes. Spatial resolution, the next criterion, describes the spacing of the detectors. Speed and Volume Accuracy, are each expressed as the mean absolute percent error. Availability defines the percentage of time a device is functioning. The availability required by each profile translates into the devices failing for only 10 hours per year. The last criterion, Point vs. Probe, indicates whether data must be collected for each vehicle that passes by a certain point, or if only a sample of representative data is adequate.

	Profile 1: Real-Time/Operations Data		
	1A: Tier 1	1B: Tier 2	1C: Ramp Metering
Element	Speed, Volume, Occupancy	Speed, Travel Time	Speed, Volume, Occupancy
Temporal Resolution	1 minute	1 minute	1 minute
Spatial Resolution	Link Level, Lane By Lane	Section Level	Link Level, Stream[2,3]
Speed Accuracy[1]	20%	20%	20%
Volume Accuracy[1]	10%	N/A	10%
Availability	99.9%[4]	99.9%[4]	99.9%[4]
Point vs. Probe	Point	Point or Probe	Point

Notes:

1. Accuracy expressed as mean absolute percent error (MAPE).
2. For stream-level resolution, lane-by-lane measurement is not needed.
3. Also mainline detection either immediately upstream or downstream of metered ramp, depending on the

requirements of metering algorithm, plus stop bar passage and presence, and queue spillback detection.

4. Approximately 10 hours down time per year.

	Profile 2: Off-Line Operations Analysis/Performance Measures		
	2A: Tier 1	2B: Tier 2	2C: Ramp Metering
Element	Speed, Volume, Occupancy	Speed, Travel Time	Speed, Volume, Occupancy
Temporal Resolution	5 minute	5 minute	5 minute
Spatial Resolution	Link Level, Lane By Lane	Section Level	Link Level, Stream[2,3]
Speed Accuracy[1]	20%	20%	20%
Volume Accuracy[1]	10%	N/A	10%
Availability	99.9%[4]	99.9%[4]	99.9%[4]
Point vs Probe	Point	Point or Probe	Point

<u>Notes:</u>

1. Accuracy expressed as mean absolute percent error (MAPE).
2. For stream-level resolution, lane-by-lane measurement is not needed.
3. Also mainline detection either immediately upstream or downstream of metered ramp, depending on the requirements of metering algorithm, plus stop bar passage and presence, and queue spillback detection.
4. Approximately 10 hours down time per year.

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
VDOT NRO Traffic Management Center Operators	TMC Operators need to be able to quickly identify anomalies in traffic patterns on freeways and key arterials in order to: (1) detect and respond to incidents and (2) provide accurate and timely traveler information to the general public.	**4.1.1 Monitor Congestion Levels**	**4.1.1.a**	Profile 1B: Real-Time/Operations Data – Tier 2 With 1-minute temporal resolution	All freeways.
	TMC Operators need to be able to quickly identify anomalies in freeway traffic patterns to manage capacity across multiple transportation modes (freeways, arterials, rail, bus, etc.)	**4.1.2 Integrated Corridor Management**	**4.1.2.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways.
	TMC Operators need more automated tools to make them more efficient so they may monitor more miles of freeway than they are currently able.	**4.1.3 Improve Operator Efficiency**	**4.1.3.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways.
	TMC Operators need real time traffic flow data to determine when to turn ramp meters on and off and when to override pre-set metering rates in real-time.	**4.1.4 Operate Ramp Meters**	**4.1.4.a**	Profile 1C: Real-Time/Operations Data – Ramp Metering	Portions of freeways with metered ramps.

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
	TMC Operators need a reliable means of being alerted when ramp queue extends onto arterials so that metering rates can be adjusted in real-time to accommodate traffic conditions.	**4.1.5 Ramp Meter Queue Alerts**	**4.1.5.a**	Profile 1C: Real-Time/Operations Data – Ramp Metering	Portions of freeways with metered ramps.
	TMC Operators need to be able to determine when to override regular HOV hours and open HOV lanes to all traffic during major incidents or emergencies.	**4.1.6 Operate HOV Facilities**	**4.1.6.a**	Profile 1A: Real-Time/Operations Data – HOV	I-66, I-395, and I-95
	TMC Operators need to be able to determine when to reverse the direction of flow on reversible flow facilities.	**4.1.7 Operate Reversible Flow Facilities**	**4.1.7.a**	Profile 1A: Real-Time/Operations Data – HOV	I-395 and I-95
	TMC Operators need to be alerted of wrong-way traffic in reversible lanes.	**4.1.8 Wrong-Way Traffic Alerts**	**4.1.8.a**	Profile 1A: Real-Time/Operations Data –HOV Plus mainline detection that can determine the direction of traffic	I-395 and I-95
	TMC Operators need to determine when to open controlled lanes to traffic.	**4.1.9 Operate Controlled (Shoulder) Lanes**	**4.1.9.a**	Profile 1B: Real-Time/Operations Data – Tier 2	I-66 from I-495 to Rt. 28
	TMC Operators need to be able to show real-time travel times between certain points of interest on DMS message boards, 511, and other dissemination tools in order to alert travelers of traffic delays.	**4.1.10 Provide Travel Times**	**4.1.10.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways.

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
	TMC Operators need an automated system that will actively lower speed limits in response to real-time traffic conditions to alleviate and delay congestion along freeways.	**4.1.11 Actively Manage Speed Limits**	**4.1.11.a**	Profile 1B: Real-Time/Operations Data – Tier 2	Merge areas.
	TMC Operators need to be able to monitor the effectiveness of an automated system that will warn drivers of stopped vehicles ahead.	**4.1.12 Provide Queue Warning**	**4.1.12.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways.
	TMC Operators need to display occupancy information for park and ride lots to alert drivers as to whether the lot is full.	**4.1.13 Manage Parking**	**4.1.13.a**	Detection in parking facilities shall maintain an accurate count of the number of available parking spaces in real-time in order to post "LOT FULL" on DMS to notify travelers prior to exiting the freeway.	Park and Ride Lots
	TMC Operators need to be able to monitor traffic conditions and respond to incidents on all evacuation corridors during an evacuation.	**4.1.14 Monitor/Facilitate Evacuation**	**4.1.14.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways and evacuation arterials.
	TMC Operators need to inform travelers of current traffic levels with particular attention to how they deviate from what is normal.	**4.1.15 Provide Traveler Information**	**4.1.15.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways.
	TMC Supervisors need to use historical traffic data to set allowable hours for scheduled maintenance or construction.	**4.1.16 Plan for Maintenance or Construction**	**4.1.16.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2	All freeways.
	Supervisors need to evaluate construction's impact on traffic.	**4.1.17 Manage Major Roadwork**	**4.1.17.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways.

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
VDOT NRO Freeway Engineers	Freeway Engineers need to evaluate the effectiveness of traffic management and incident management strategies.	**4.2.1 Evaluate Effectiveness of Traffic Control**	**4.2.1.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2	All freeways.
	Freeway Engineers need to evaluate HOV lane usage in order to set policy with respect to when the HOV lanes should be in effect.	**4.2.2 Evaluating HOV Lanes Hours of Operation**	**4.2.2.a**	Profile 2A: Off-Line Operations Analysis/Performance Measures – HOV	I-66, I-395, and I-95
	Freeway Engineers need to evaluate controlled lane usage in order to set policy with respect to when controlled lanes should be open to traffic.	**4.2.3 Evaluating Controlled (Shoulder) Lanes Hours of Operation**	**4.2.3.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2	I-66 from I-495 to Rt. 28
	Freeway Engineers need to measure HOV person-throughput between each interchange.	**4.2.4 Measure HOV Throughput**	**4.2.4.a**	Profile 2A: Off-Line Operations Analysis/Performance Measures – HOV	I-66, I-395, and I-95
	Freeway Engineers need to measure and report on the differences in speed in HOV lanes and GP lanes between each interchange.	**4.2.5 Measure HOV Speeds versus GP Speeds**	**4.2.5.a**	Profile 2A: Off-Line Operations Analysis/Performance Measures – HOV	I-66, I-395, and I-95

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
	Freeway Engineers need to determine when to reverse the direction of flow on reversible lanes based on historical traffic patterns. This may be of particular interest on weekends, where the dominant direction of flow may be less predictable than on weekdays.	**4.2.6 Evaluate Reversible Lane Operations**	**4.2.6.a**	Profile 2A: Off-Line Operations Analysis/Performance Measures – HOV	I-395 and I-95
	Freeway Engineers need to set policy with respect to ramp metering rates and control modes (e.g., traffic-responsive vs. time-of-day).	**4.2.7 Monitor Ramp Meter Operations**	**4.2.7.a**	Profile 2C: Off-Line Operations Analysis/Performance Measures – Ramp Metering	Metered Ramps.
	Freeway Engineers need to measure ramp volumes for analysis and potential policy changes to metering rates.	**4.2.8 Measure Ramp Volumes**	**4.2.8.a**	Profile 2C: Off-Line Operations Analysis/Performance Measures – Ramp Metering	Ramps.
	Freeway Engineers need to detect mainline traffic flows to adjust standard metering rates.	**4.2.9 Detect Mainline Traffic Flows**	**4.2.9.a**	Profile 2C: Off-Line Operations Analysis/Performance Measures – Ramp Metering	Portions of freeways with metered ramps.
	Freeway Engineers need to assess where, when, and how often ramp meter queues spillback onto arterial streets.	**4.2.10 Queue Alerts**	**4.2.10.a**	Profile 2C: Off-Line Operations Analysis/Performance Measures – Ramp Metering	Metered Ramps.
	Freeway Engineers need to evaluate construction's impacts to traffic.	**4.2.11 Evaluate Effects of Roadwork**	**4.2.11.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2	All freeways.

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
	Freeway Engineers need to set policy with respect to when the controlled (shoulder) lanes should be open to traffic.	**4.2.12 Monitor Lane Control**	**4.2.12.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2	I-66 from I-495 to Rt. 28
VDOT NRO Traffic Signal Operations Engineers	Traffic Signal Operations Engineers need to be able to quickly identify anomalies in arterial traffic patterns to manage capacity across multiple transportation modes (freeways, arterials, rail, bus, etc.).	**4.3.1 Integrated Corridor Management**	**4.3.1.a**	Profile 1B: Real-Time/Operations Data – Tier 2 Plus 5-minute volumes on key freeway exit ramps	All freeways and arterials.
	Traffic Signal Operations Engineers need to detect volumes on arterials (15 minute intervals) to evaluate whether to switch timing plans in real-time.	**4.3.2 Detect Volumes in Real-Time**	**4.3.2.a**	At 15-minute intervals from arterial stop bar or system detectors	All arterials.
	Traffic Signal Operations Engineers need to monitor key turning movements on detour routes in real-time.	**4.3.3 Monitor Turning Movements**	**4.3.3.a**	No detection requirements. Need met through CCTV camera surveillance.	Key arterial intersections.
	Traffic Signal Operations Engineers need to be able to use archived data to optimize the signal timing plan for a corridor.	**4.3.4 Optimize Signal Phasing and Timing**	**4.3.4.a**	At 15-minute intervals from arterial stop bar or system detectors	All arterials.
VDOT Continuous Count Program	The Continuous Count Program needs to be able to collect continuous traffic volume data between each freeway interchange.	**4.4.1 Collect Complete Data**	**4.4.1.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2 At 15-minute intervals	All freeways.

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
	The Continuous Count Program needs to be able to detect within a day whether any detector is malfunctioning.	**4.4.2 Collect Reliable Data**	**4.4.2.a**	Detector data shall be uploaded to ADMS no less than once per day.	All freeways.
	The Continuous Count Program needs to be able to collect daily data for no greater than 15 minute time intervals.	**4.4.3 Collect Data Daily**	**4.4.3.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2 At 15-minute intervals	All freeways.
	The Continuous Count Program needs to collect vehicle classification data at a sample of locations.	**4.4.4 Vehicle Classification**	**4.4.4.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2 Plus volumes by FHWA vehicle classifications	All freeways.
VDOT NRO Maintenance Division	The maintenance division needs to receive fewer work orders.	**4.5.1 Minimize Maintenance Work Orders**	**4.5.1.a**	Devices must have voltage smoothing UPS.	All freeways and arterials.
			4.5.1.b	Devices must have protection from lightning and electrical surges.	
			4.5.1.c	Devices must have independent power supplies.	
			4.5.1.d	Devices at key locations must have a generator plug.	
			4.5.1.e	All power and communication cables must be protected against line breaks.	
			4.5.1.f	All field devices shall be out of reach or located in cabinets to avoid vandalism.	
			4.5.1.g	All field devices shall be on stable foundations on level ground to prevent erosion and undermining.	
			4.5.1.h	All device components shall be rated for 5 years of continuous operation.	
			4.5.1.i	All device components shall be robust and waterproof.	
	The maintenance division needs the ability to troubleshoot and solve simple maintenance problems remotely to reduce trips to the field.	**4.5.2 Troubleshoot Detector Problems Remotely**	**4.5.2.a**	Devices must be capable of having remote modem reset.	All freeways and arterials.
			4.5.2.b	Devices must be capable of being tested and troubleshooted remotely.	
	The maintenance division needs to be able to perform routine maintenance and repairs quickly when trips	**4.5.3 Perform Routine Maintenance and Repairs Quickly**	**4.5.3.a**	Devices must have parts that are easy to remove, replace, and service in the field.	All freeways and arterials.
			4.5.3.b	Devices must be of consistent models for easy replacement of parts.	

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
	to the field are necessary.		**4.5.3.c**	Devices must have replacement parts readily available.	
	The maintenance division needs safe conditions for technicians maintaining devices in the field.	**4.5.4 Safe Conditions**	**4.5.4.a**	There must be a stable parking space on the shoulder at all device locations.	All freeways and arterials.
			4.5.4.b	Devices must be accessible without requiring lane closures.	
			4.5.4.c	Devices shall not be located in a median except for rare circumstances.	
			4.5.4.d	Devices shall be placed away from the edge of pavement and when possible behind a guardrail.	
			4.5.4.e	Devices shall be placed out of high incident locations.	
	The maintenance division needs to develop and continuously update a formal detector inventory and lifecycle management system.	**4.5.5 Inventory/Lifecycle Replacement**	**4.5.5.a**	All devices and components shall be bar coded in accordance with NRO Inventory Barcode Requirements.	All freeways and arterials.
			4.5.5.b	All field equipment must be logged in the IMMS.	
			4.5.5.c	All replacement parts must be logged in the IMMS.	
VDOT NRO Traffic Engineering	The needs for Traffic Engineering staff are largely those already listed under Freeway Engineers. Additional needs for Traffic Engineering staff are for spot studies for safety, signal warrants, etc. However, these studies do not require continuous data collection and by their nature, their locations are unpredictable.	**4.6.1**	**4.6.1.a**	(See High Level Requirements 4.2.1 through 4.2.12)	
VDOT NoVA, Fredericksburg, and Culpeper District Transportation Planning	Transportation Planning needs high quality historic and current traffic flow data to ensure that it has accurate forecasting with which to set in place future policies and planning.	**4.7.1 Perform Accurate Forecasting**	**4.7.1.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2 At 15-minute intervals	All freeways and arterials.

User Class	User Need	ConOps Section	High-Level Requirement ID	High-Level Requirement	Applies To
	Transportation Planning needs high quality origin and destination trip data to ensure that it has accurate forecasting with which to set in place future policies and planning.	**4.7.2 Collect Origin/Destination Data**	**4.7.2.a**	No Requirement. Origin/Destination data does not warrant the deployment of specific detectors, but would be a result provided by detectors deployed to meet other specific user needs.	All freeways and arterials.
	Transportation Planning needs high quality historic and current traffic flow data to verify that its studies are accurate in order to reinforce its decisions regarding policies and planning.	**4.7.3 Study Validation**	**4.7.3.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2 At 15-minute intervals	All freeways and arterials.
	Transportation Planning needs to know whether and how often a lot is full to be able to determine if additional lots are needed and where they should be located.	**4.7.4 Monitor Park and Ride Lots**	**4.7.4.a**	Detection in parking facilities shall maintain an accurate count of the number of available parking spaces in real-time.	Park and Ride Lots
Private Sector	The private sector needs high quality speed data to provide traveler information.	**4.8.1 Provide Traveler Information**	**4.8.1.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways and arterials.
Program Managers	Program Managers need access to performance measures for use in strategically managing investments.	**4.9.1 Managing Investments**	**4.9.1.a**	Profile 2B: Off-Line Operations Analysis/Performance Measures – Tier 2	All freeways and arterials.
Regional Media Outlets	Regional Media Outlets need to disseminate accurate incident and traffic information to the traveling public.	**4.10.1 Disseminating Information**	**4.10.1.a**	Profile 1B: Real-Time/Operations Data – Tier 2	All freeways and arterials.

"Applies to" may be:

1. All freeways
2. Specific bundles only
3. Locations where a specific application is planned
4. Key arterials, specified by bundle

Virginia Department of Transportation
Contract# 27090 (Task NRO-27090-007)

Vehicle Detector Master Plan

Virginia Department of Transportation Northern Region Operations

Prepared by:

Kimley-Horn and Associates, Inc.

June 13, 2008

TABLE OF CONTENTS

1 Introduction / Background / Project Overview ... 1

2 Existing Conditions & Planned Near-Term Projects ... 2

2.1 NRO Deployment Bundles ... 2
2.2 Location of Existing Detectors ... 4
2.3 Sources of Future Detection ... 8

3 Prioritization Criteria and Analysis ... 11

3.1 Base NRO Prioritization ... 11
3.2 Criteria for use in Prioritization of Detector Deployments ... 12
3.3 Revised Bundle Prioritization Scoring ... 13
3.4 Device Spacing and Placement Considerations ... 17
3.5 Cost Considerations ... 21

4 Future Considerations ... 25

5 High-Level Summary of Recommendations ... 25

LIST OF FIGURES

Figure 1. NRO Corridor Bundles and Existing Active Detection Zones ... 6
Figure 2. Existing Active Detection Zones – View of Current Coverage Area ... 7
Figure 3. I-95 Corridor Coalition Core Coverage in Northern Virginia ... 9
Figure 4. High-Level Detection Requirements by Bundle ... 16
Figure 5. Aggregating Traffic Detector Data to Different Geographic Sites ... 19
Figure 6. Short links whose limits are determined by geometry ... 20
Figure 7. Links on longer homogenous sections whose lengths are capped at 1 mile ... 20
Figure 8. Detection zones for ramp metering ... 21

LIST OF TABLES

Table 1. Corridor Bundle Segment Breakdown ... 2
Table 2. Existing Detector Stations and Zones by Route ... 5
Table 3. NRO Office of Systems Design Bundle Prioritization ... 12
Table 4. NRO Corridor Bundle Rankings for Detection ... 14
Table 5. High-Level Requirements Profiles ... 17
Table 6. NRO Bundles Mileage Breakdown ... 21
Table 7. Estimates of Detector Quantities ... 22
Table 8. Cost Estimates from Regional Vendors for Point Detectors ... 24
Table 9. Simplified Cost Estimates and Expected Life Cycle of Point Detectors ... 24

1 INTRODUCTION / BACKGROUND / PROJECT OVERVIEW

This Detector Master plan presents a logical progression for the Virginia Department of Transportation (VDOT) Northern Region Operations (NRO) to expand the coverage area of its traffic data collection network. It is based upon the needs of the various stakeholders, which includes groups within NRO, VDOT Central Office and private sector consumers and providers of traffic data. In the development of this document several groups were interviewed in one-on-one or small group settings in order to understand the breadth of current use and future needs for traffic data. In most cases the future needs are those that the VDOT NRO Traffic Management Center (TMC) operators and VDOT NRO Freeway Engineers have for information obtained through a detector system, although the ability to maintain the field infrastructure is an important consideration as well.

For purposes of this document, the detection system includes the collective deployment of sensors that directly measure traffic flow data such as speed, volume, occupancy, vehicle classification or travel time. It may consist of point detection, probe-vehicle detection or a combination of both. It may consist of data from agency-owned detectors or private sector data providers. This document summarizes the prioritization criteria, the basis for device spacing, and an estimate of cost for installation and upkeep on an annual basis over an assumed ten-year life of a detector. This document is intended to supplement the GIS mapping for the proposed detector locations to better understand the reasons for the various locations that have been identified.

2 EXISTING CONDITIONS & PLANNED NEAR-TERM PROJECTS

2.1 NRO Deployment Bundles

The following section describes the existing active detector locations in the NRO. Corridor segments have been combined to form corridor bundles. These bundles group key segments of roadways that are parallel routes and interstates as well as the key routes that connect them together. Based on current traffic demands, these bundles include all key routes that should be considered for detection coverage. Roadways not included in these bundles should be evaluated again in the future based on demand and the marginal per-mile cost of traffic data in the future. **Table 1** lists the routes that comprise each corridor bundle. **Figure 1** displays a map of the corridor bundles in the region with existing detection shown. These bundles were originally developed by the NRO prior to the May 2008 realignment of operating region boundaries. Impacts of that realignment are noted. For the Detector Master Plan, two minor modifications were made. First, Bundle H was subdivided into Bundles H1 and H2 to correspond with the limits of existing detection. Second, Bundle N was subdivided into Bundles N1, N2 and N3 to correspond with HOT Lanes project limits.

Table 1. Corridor Bundle Segment Breakdown

DISTRICT	BUNDLE	BUNDLE DESCRIPTION
NOVA	**A**	I-395: DC Line to I-495 Rt. 110: Rt. 1 to I-66 GW Pkwy: DC Line to I-495 (non VDOT)
NOVA	**B**	I-95: I-495 to Rt.123 Rt.1: I-495 to Rt.123 Rt. 235
NOVA	**C**	I-95 & Rt 1 in Prince William County
FRED	**D**	I-95 & Rt 1 in Stafford County
FRED	**E**	I-95 & Rt 1 in Spotsylvania County Rt.208 in Spotsylvania County
NOVA	**F**	I-66: DC Line to I-495 Rt.267: I-66 to I-495 Rt. 29: DC Line to I-495 Rt. 50: DC Line to I-495
NOVA	**G**	I-66: I-495 to Rt. 50 Rt.29: I-495 to Rt. 50 Rt.50: I-495 to I-66 Rt.123: Rt. 7 to Rt.236 Rt.243: 123 to Rt. 29
NOVA	**H1**	Rt.66: Rt.50 to Bull Run Rt.29: Rt.50 to Bull Run Rt.234: N of Rt. 29 to S of I-66
NOVA	**H2**	Rt.66: Bull Run to Rt.15 Rt.29: Bull Run to Rt.15 Rt.234: N of Rt. 29 to S of I-66

DISTRICT	BUNDLE	BUNDLE DESCRIPTION
NOVA	**I**	Rt.215: Rt.29 to Rt.28 Rt.234: I-66 to I-95 Rt.28: from Rt.234 to Prince William Co.
CULP	**J**	I-66: Rt. 15 to I-81
NOVA	**K**	DTR: I-495 to Rt.28 (non VDOT) Rt.7: I-495 to Rt.28 FfxCo. Pkwy (Rt.7100) Rt.7 to DTR Rt.28: Rt. 7 to DTR
NOVA	**L**	DTR & Dulles Greenway: Rt.28 to Rt. 15 Leesburg (Non VDOT) Rt.7: Rt.28 to Rt.15 Rt.15: Leesburg & Rt.7 zone
NOVA	**M**	Rt. 7: Rt. 15 Leesburg to NRO boundary Rt. 9: Rt. 7 to NRO boundary Rt. 287: Rt. 9 to Rt. 7
NOVA	**N1**	I-495 (Capital Beltway): American Legion Bridge to Rt. 267
NOVA	**N2**	I-495 (Capital Beltway): Rt. 267 to I-395
NOVA	**N3**	I-495/I-95: I-395 to Woodrow Wilson Bridge
NOVA	**O**	Rt.7100: DTR to I-95 Rt. 123: Rt. 7100 to I-95
NOVA	**P**	Rt.3000: Rt.28/234 to I-95 Rt.28: DTR to I-66 Rt.28: I-66 to Rt.234/3000
NOVA	**Q**	Rt.15: NRO boundary to Rt. 29 Rt.234: Rt.15 to Rt.29
FRED	**R**	Rt. 218 Rt. 3: Rt. 20 to I-95 Rt. 3: Rt.17 to King George boundary Rt. 301: Rt. 3 to King George boundary
CULP	**S**	Rt.3: Rt.20 to Rt.29 Rt.29: Rt.3 to Madison County
CULP	**T**	Rt.15: Rt.29 to Rt.3 Rt.29: Rt.15 to Rt.215
CULP	**U**	Rt.17 & Rt.28 in Fauquier County
CULP	**V**	Rt.211: Rt.29 to Rappahannock County
NOVA	**W**	Rt.50: I-66 to Rt.15
NOVA	**X**	Rt.236: Rt. 1 to Rt. 50/29 Rt.7: Rt.1 to I-395
NOVA	**Y**	Rt.244: Rt.27 to Rt.236 Rt.620: Rt.236 to Rt.7100
NOVA	**Z**	Rt.193: from Rt. 7 to Rt.90005 Rt.123: from Rt. 267 to 90005
FRED	**AA***	I-95 & Rt 1 in Caroline County
STAUNTON	**AB***	I-66 in Warren County

Notes:

Bundle H was subdivided into Bundles H1 and H2 to correspond with the limits of existing detection.

Bundle N was subdivided into Bundles N1, N2 and N3 to correspond with HOT Lanes project limits.
The starred (*) bundles were recently reassigned to the NRO from other regions.
The shaded bundles were recently reassigned to the NWRO from the NRO.

In May 2008, VDOT's operating regions were realigned to include more miles of freeway corridors in the NRO and shift some of the more rural roads to the west to the Northwestern Region Operations (NWRO). Specifically, Culpeper, Fauquier, Orange, Madison, and Rappahannock Counties were reassigned from NRO to the NWRO. However, the NRO has retained responsibility for I-66 in Fauquier County and added responsibility for I-66 in Warren County out to I-81. Also, I-95 and Route 1 within Caroline County were reassigned from Central Region Operations to the NRO.

As a result of this realignment, bundles S and V were removed from further consideration in this master plan and two new bundles, Bundles AA and AB, were created for I-95/US 1 in Caroline County and I-66 in Warren County, respectively. For this master plan, we still consider the bundles that are no longer part of NRO in addition to the two newly defined bundles. These bundles were reduced in priority below all ITS bundles that are within the new NRO boundaries. That being said, the more rural routes being reassigned to the NWRO were of a very low priority for detector deployments anyway.

Bundle AA was placed in the priority listing based on having an AADT of 85,000 vehicles per day, five TMC operator wish list locations, no other ITS, and assumed crash rates and weighted levels of service 90% of the adjacent Bundle E. Bundle AB was placed in the priority listing based on having an AADT of 37,000 along its busiest segment, no other ITS, and assumed crash rates and weighted levels of service 90% those of the adjacent Bundle J.

2.2 Location of Existing Detectors

The existing agency-owned detection network, which includes the combined IDS, CMS, and RMS subsystems, consists of over 380 stations comprising over 1170 point detectors. **Table 2**, **Figure 1** and **Figure 2** provide a high-level view of the locations of existing devices within NRO. The figures differentiate agency-owned detectors by the type of detection technology and private sector or other agency (non-NRO) detectors. Not shown are approximately 100 SpeedInfo detectors being planned for I-495, I-66 and I-95. Final locations for these have not yet been determined and being highly portable in nature, they could be relocated depending on VDOT's detection plans.

While there are several NRO detectors on I-495, nearly all of these are inactive or decommissioned except for a few newer sensors clustered around the Springfield Interchange; the vast majority of active detectors are on I-66, I-95 and I-395. Existing detection on I-66 extends out to the Fairfax/Prince William county line; detection on I-95 extends to Aquia in Stafford County. While not maintained by NRO, VDOT also has a number of continuous count stations in the region that are used for statewide traffic volume and vehicle classification reporting.

Table 2. Existing Detector Stations and Zones by Route

Route	Approx Miles*	Active Stations	Active Zones
I-395	19	31	186
I-495	42	17	79
I-66	54	221	389
I-95	38	111	285

* - *Mileage is approximate and only considers the lengths of I-66 and I-95 with existing detection*

The vast majority of existing NRO detectors are inductive loops. These loops need to be replaced every time the road surface is repaved and as a result, the expected life of existing loops is limited. Therefore, their specific locations do not have a major bearing on this master plan. That being said, the existing coverage areas are linked to traffic data needs identified in the Concept of Operations. As a result, the existing instrumented corridors correspond with the high priority corridors as determined by this master plan. This prioritization will be presented in Section 3. In addition, existing coverage areas already have the infrastructure for future detection (e.g., cabinets, fiber access points) so this makes detector replacement less expensive than new deployments. This will also be discussed in Section 3.

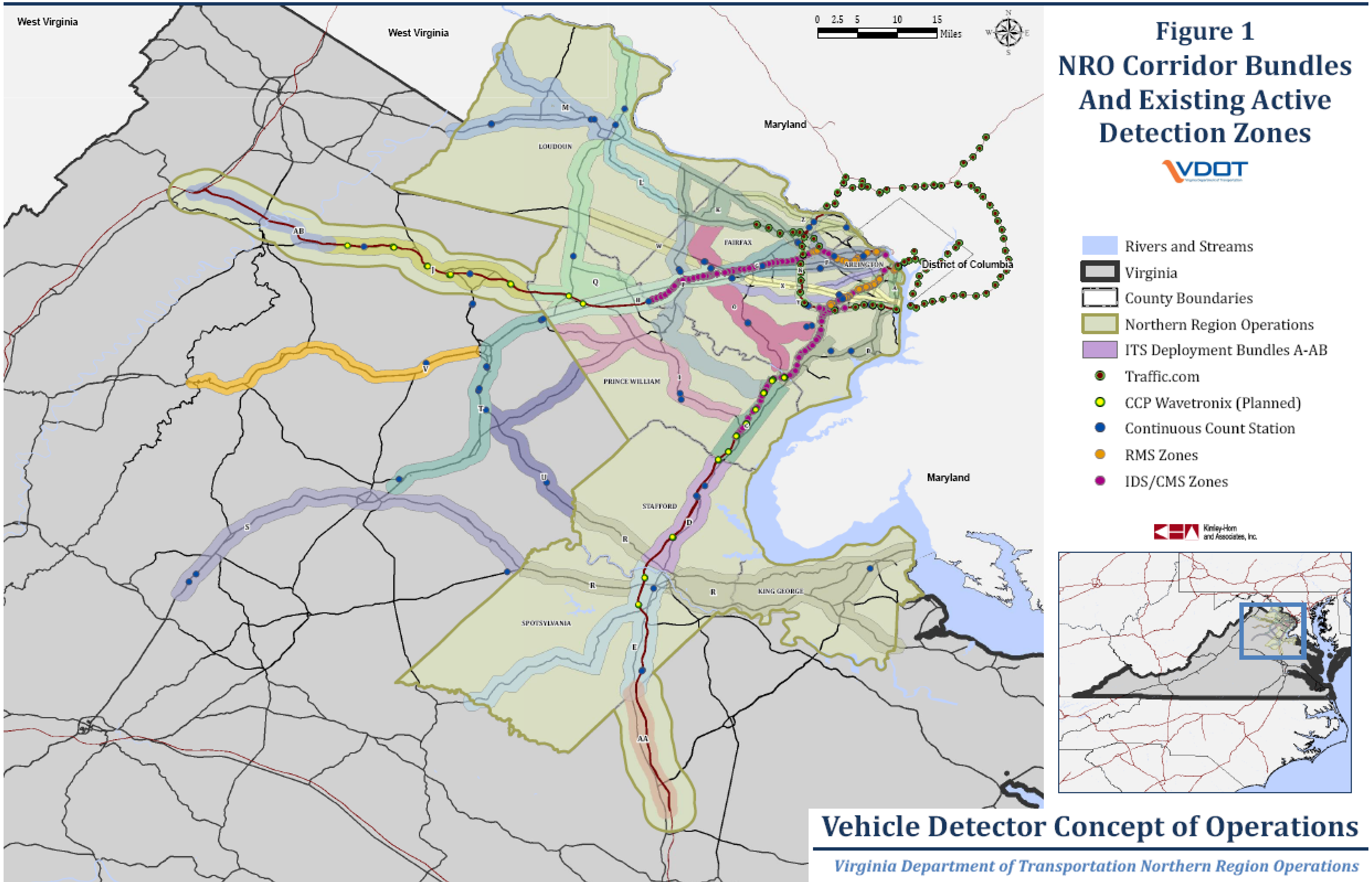

Figure 1. NRO Corridor Bundles and Existing Active Detection Zones

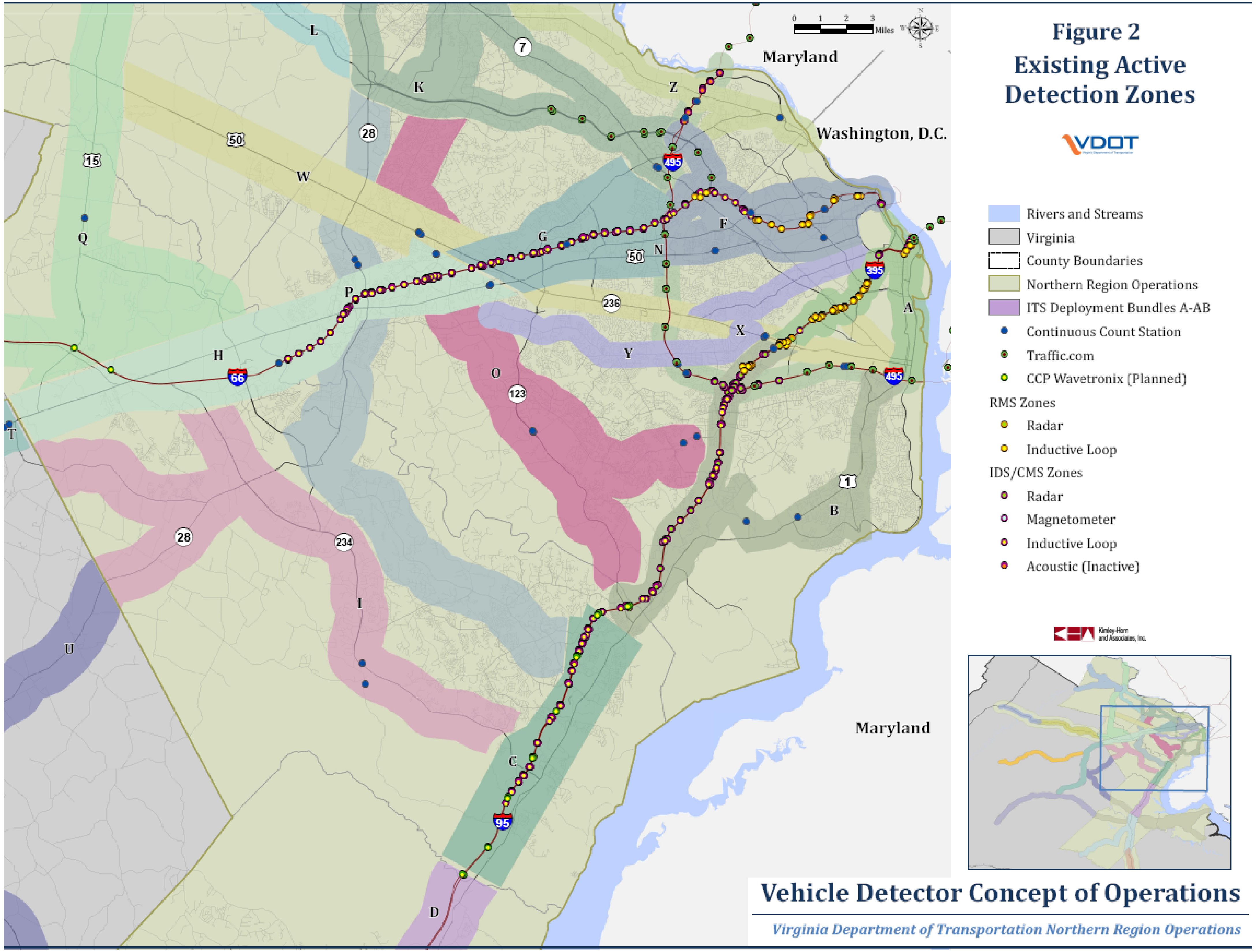

Figure 2. Existing Active Detection Zones – View of Current Coverage Area

2.3 Sources of Future Detection

At the time of this writing, there are several identified sources of detection on NRO routes that come from third parties. These represent an opportunity to leverage other interests and focus the limited resources of NRO elsewhere.

2.3.1 Continuous Count Program Detector Expansion

The VDOT Continuous Count Program (CCP) is responsible for collecting average daily traffic volume by vehicle classification. Currently, the CCP has 75 detector stations in the Northern Region. These are shown in **Figure 2**. NRO has an opportunity to use this data for operations barring some technological hurdles that must be addressed (e.g., different polling rates, necessary firmware upgrades). In addition to these, the CCP is planning to deploy 36 Wavetronix detectors to supplement its current deployment, mainly beyond the existing coverage on I-66 and I-95. NRO will be able to use these for operations in the same way as any other detector. These additional detectors will be primarily in bundle C (I-95 in Prince William County), though there are a few planned in bundles B (I-95 in Fairfax County) and on I-66 to the west beyond the limits of existing detection H.

2.3.2 SpeedInfo

A private company, SpeedInfo, has developed a low-cost Doppler radar detector that runs solely on solar power and communicates via cellular modem with the companies servers in California where it aggregates the data. The sensor does not measure traffic continuously, nor does it differentiate between lanes, which makes it unsuitable to be the primary means of detection for Tier 1 routes given the requirements to differentiate HOV and general purpose lanes. However, it is a highly portable and easy-to-install sensor that can measure speeds. SpeedInfo's business objective in Washington, D.C., area is to build out a regional sensor network using its own capital and marketing that data to regional agencies for homeland security applications.

In NRO, SpeedInfo has been working with VDOT to identify 100 locations where it can supplement VDOT's detector network and provide that data to VDOT for free. The locations for these sensors have not yet been finalized, but are envisioned to encompass I-495 and parts of I-95 and I-66 inside the beltway.

2.3.3 Traffic.com

Through a Congressional earmark, Traffic.com was funded to deploy vehicle detectors in major metropolitan areas across the U.S. In the Washington, D.C., area Traffic.com has deployed 100 detectors, 30 of which are in Virginia. These are located on I-495 and the Dulles Toll Road. Given that new detectors are being installed for the HOT lanes project on I-495 (see below), Traffic.com will likely move its detectors to other routes. Those plans have not yet been determined, however.

2.3.4 Inrix

Inrix has recently signed a contract to provide probe-based traffic data to the I-95 Corridor Coalition, of which VDOT is a member state. Inrix contracts with fleets that monitor their individual vehicles with GPS technologies. Using this, combined with other data as available—including public sector point data—Inrix estimates travel times. While VDOT has access to the terms and conditions and cost schedule from the I-95 contract, Inrix holds closely to its data sources, algorithms and methods for fusing disparate data. As a result, data quality must be determined through ground truth data collection.

Under the terms of the contract, which would apply to VDOT, data for the core coverage area would be available in July 2008 and cost $750 per centerline mile per year, plus an initial $150 per centerline mile in the first year. Core coverage includes 625 miles on the following freeways: I-95, I-395, I-495, and I-66 up to the 234 Bypass. Arterials include Route 123, Route 234, and portions of Rt 29, 15 and 17. The geographic coverage area can also be expanded to other routes through the contract through a process defined by the Coalition. It must be noted that it is not known at this time whether this data meets the high-level requirements defined for detector data in terms of temporal and spatial resolution, accuracy or availability.

The coverage area under the terms of the contract is shown in Figure 3.

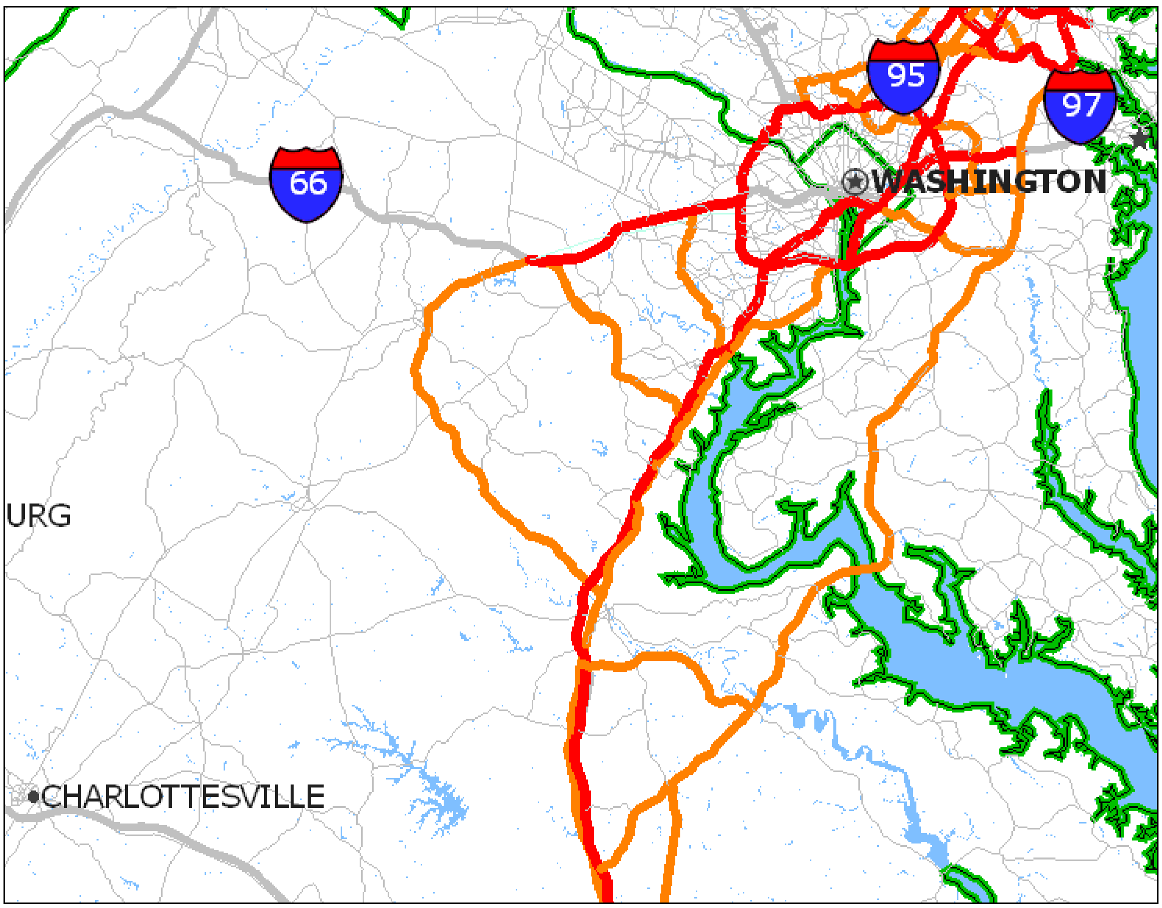

Figure 3. I-95 Corridor Coalition Core Coverage in Northern Virginia

2.3.5 I-495 High Occupancy Toll (HOT) Lanes

In a public-private partnership between VDOT and Flour/Transurban, the private consortium will construct, operate and maintain HOT lanes on I-495 on Bundle N2. The project is currently in the design phase. New lanes will be added that will have toll rates that vary based on real-time demand to ensure congestion-free travel. The 30% plans for I-495 have privately constructed and maintained detectors at a 1/3 mile spacing that will cover the HOT lanes and the general purpose lanes. This represents an opportunity for VDOT to receive lane-by-lane speed, volume and occupancy data at a high spatial density for no cost.

2.3.6 I-95/I-395 HOT Lanes

A HOT Lanes project similar to that for I-495 is also planned for I-95/I-395. Plans for this project are less certain, but it is likely the existing reversible lanes will be converted to toll lanes and extended southward as far as Fredericksburg. Given the similar nature of these projects and that they are being designed an operated by the same firm, it is reasonable to assume the plans for spacing and maintenance will be the same. However, this project has not progressed as far as the I-495 project so there is more uncertainty. Nonetheless, there is a large enough probability of this project occurring as expected that this project should be taken into consideration in the detection plans for this corridor.

3 PRIORITIZATION CRITERIA AND ANALYSIS

A base prioritization scheme was developed by the NRO Office of Systems Design (OSD) which ranked the corridor bundles listed in Table 1. This prioritization scheme and its results are presented in Section 3.1 and further modified in the following sections. The prioritization scheme establishes the corridor rankings for use in planning detector deployments in order of need throughout the region.

3.1 Base NRO Prioritization

The 26 corridor bundles were analyzed by NRO and given overall ITS priorities within their districts according to the formula

$$\frac{AADT}{10{,}000} * (.1D + .2E + .3F) + EX + \frac{CRASHES}{100} = SCORE$$

Where:

AADT = Average Annual Daily Traffic, veh/d

D = % of length with LOS D

E = % of length with LOS E

F = % of length with LOS F

EX = Dummy variable for existing ITS infrastructure: 8 if yes, 2 if no

CRASHES = Number of crashes on the corridor

This formula was, with one exception, the basis for the overall ITS deployment priority assigned to the 26 bundles. The one exception to prioritization by this formula was in the Culpepper District, where Bundle J was raised to the top of the priority list because of its being on an Interstate Highway, I-66, and the Office of Systems Design's desire to make that interstate corridor a model ITS corridor. The VDOT NRO base prioritization is shown in **Table 3**.

Table 3. NRO Office of Systems Design Bundle Prioritization

DISTRICT	BUNDLE	AVERAGE ANNUAL DAILY TRAFFIC (AADT)	LEVEL OF SERVICE (%)				EXISTING ITS INFRASTRUCTURE (Yes =8, No =2)	CRASH RATE	TOTAL
			D (1)	E (2)	F (3)	Weighted Average			
NOVA	**B**	200,000	10	10	80	2.70	8	409	66.1
NOVA	**A**	175,000	10	20	70	2.60	8	497	58.5
NOVA	**F**	160,000	40	10	50	2.10	8	430	45.9
NOVA	**G**	120,000	0	15	85	2.85	8	254	44.7
FRED	**D**	140,000	10	20	70	2.60	2	239	40.8
NOVA	**C**	100,000	10	0	90	2.80	8	383	39.8
NOVA	**N**	160,000	50	20	30	1.80	8	125	38.1
NOVA	**W**	120,000	30	40	30	2.00	8	203	34.0
NOVA	**P**	100,000	50	0	50	2.00	8	227	30.3
NOVA	**K**	100,000	30	0	70	2.40	2	301	29.0
NOVA	**O**	140,000	80	20	0	1.20	8	273	27.5
NOVA	**H**	80,000	40	30	30	1.90	8	345	26.7
FRED	**E**	100,000	40	50	10	1.70	2	424	23.2
NOVA	**Z**	80,000	10	80	10	2.00	2	278	20.8
NOVA	**I**	40,000	10	80	10	2.00	8	219	18.2
CULP	**T**	60,000	80	20	0	1.20	8	273	17.9
NOVA	**Y**	80,000	80	10	10	1.30	2	497	17.4
NOVA	**Q**	60,000	35	60	5	1.70	2	345	15.7
NOVA	**M**	60,000	30	65	5	1.75	2	314	15.6
CULP	**U**	60,000	50	50	0	1.50	2	215	13.2
FRED	**R**	40,000	40	50	10	1.70	2	269	11.5
NOVA	**L**	60,000	80	20	0	1.20	2	211	11.3
CULP	**S**	80,000	90	10	0	1.10	2	0	10.8
CULP	**V**	40,000	80	20	0	1.20	2	320	10.0
CULP	**J**	40,000	60	40	0	1.40	2	0	7.6

3.2 Criteria for use in Prioritization of Detector Deployments

Various characteristics of a corridor are considered for refining prioritization of detector system expansion projects. Criteria that are generally applicable to detector deployment prioritization are discussed below.

- **Detection Requirements for Specific Traffic Management Applications –** Specific applications such as ramp metering, HOV lanes and controlled/shoulder lanes have specific detection requirements for performance measurement and real-time traffic management. These locations have a higher priority for detection based on these specific needs.
- **Traffic Volume –** Daily traffic volume is a widely available measure and a good indicator of the importance of a corridor. Higher volumes typically translate to more recurring congestion and a higher frequency of accidents, given a constant accident rate per vehicle. Higher volumes also mean more people are negatively impacted by congestion delays and exposed to secondary crashes due to highway

incidents. Accordingly, a higher priority for detection is assigned to higher volume corridors.

- **Primary Importance of Freeways** – The Detector Concept of Operations Freeways identifies many more detection needs for freeways than arterial streets. While stop bar and system detectors are used for actuated traffic signal control and signal retiming, real-time applications for detection on freeways is limited to traveler information and congestion monitoring.
- **Safety Service Patrol (SSP)** – Another consideration is the existing coverage areas of Safety Service Patrol vehicles. Roadways within the SSP patrol area are more actively managed by the TMC during incidents and other events. As a result, it is more important on SSP routes to measure the effects of incidents and other performance measures because the TMC is more able to effectively use that information to improve operations.
- **Existing ITS Infrastructure** – Corridors with existing but incomplete detector coverage should be given greater priority than corridors with no existing ITS infrastructure. This is due to the availability of agency-owned communications, splice points and the ability to work alongside other ITS devices such as DMS and cameras. Existing infrastructure enables less expensive deployment.
- **Evacuation Routes** – Congestion management and incident detection and clearance are more pressing on corridors that serve as evacuation routes than on corridors that do not. However, the Northern Virginia area does not face a strongly directional evacuation hazard, as do coastal areas subject to hurricanes, and all corridors under consideration for detector deployment are major routes that may be called upon to serve as an evacuation route in the event of an emergency. Accordingly, evacuation routes are not a major criterion for prioritizing detector deployment in the NRO area.

3.3 Revised Bundle Prioritization Scoring

Based on the above prioritization criteria for detectors, the base prioritization has been modified. Bundles identified as Tier 1 and those with ramp meters, given their detection requirements from the Concept of Operations, are given the highest priority. Beyond this, the bundles are prioritized based on their base ranking as shown in Table 3. Bundles no longer part of the NRO are listed at the bottom of the priority listing. The final bundle prioritization is listed in **Table 4** and shown graphically in **Figure 3**.

These priorities do not reflect the opportunities for data from external sources as identified in Section 2.3; these opportunities should be viewed as a means to enable VDOT to reallocate its budget to increased density as needed or to geographic expansion.

Table 4. NRO Corridor Bundle Rankings for Detection

DISTRICT	BUNDLE	BASE PRIORITY RANKING	BUNDLE DESCRIPTION	HIGH-LEVEL REQUIREMENT PROFILE***	AVERAGE ANNUAL DAILY TRAFFIC (AADT)	CONTROL ACCESS (Yes/No)	EXISTING DETECTORS (Yes/No)**	APPLICATION	SSP	Opportunity / Consideration
NOVA	**B**	1	I-95: I-495 to Rt.123 Rt.1: I-495 to Rt.123 Rt. 235	1A: HOV	200,000	Y	Y	RHOV Lanes	SSP	I-395/I-95 HOT Lanes: expected operational in 2015
NOVA	**A**	2	I-395: DC Line to I-495 Rt. 110: Rt. 1 to I-66 GW Pkwy: DC Line to I-495 (non VDOT)	1A: HOV; 1D: Ramp Metering	175,000	Y	Y	RHOV Lanes, Ramp Meters	SSP	I-395/I-95 HOT Lanes: expected operational in 2015
NOVA	**F**	3	I-66: DC Line to I-495 Rt.267: I-66 to I-495 Rt. 29: DC Line to I-495 Rt. 50: DC Line to I-495	1D: Ramp Metering	160,000	Y	Y	Ramp Meters	SSP	Traffic.com detectors on Rt. 267
NOVA	**G**	4	I-66: I-495 to Rt. 50 Rt.29: I-495 to Rt. 50 Rt.50: I-495 to I-66 Rt.123: Rt. 7 to Rt.236 Rt.243: 123 to Rt. 29	1A: HOV	120,000	Y	Y	HOV Lanes, Shoulder Lanes	SSP	Active Traffic Management being studied on this corridor.
NOVA	**C**	6	I-95 & Rt 1 in Prince William County	1A: HOV	100,000	Y	Y	RHOV Lanes	SSP	I-395/I-95 HOT Lanes: expected operational in 2015
NOVA	**N1**	7	I-495: American Legion Bridge to Rt. 267	1B: Tier 1	185,000	Y	Y		SSP	Potential for Traffic.com to take over inactive acoustic detectors
NOVA	**N2**	7	I-495: Rt. 267 to I-395	1B: Tier 1	175,000	Y	Y	HOT Lanes	SSP	HOT Lanes expected operational in 2013, Traffic.com & SpeedInfo detectors
NOVA	**N3**	7	I-95/I-495: I-395 to Woodrow Wilson Bridge	1B: Tier 1	145,000	Y	Y		SSP	Variable Speed Limit project during Eisenhower/Telegraph construction (2008-2012); Traffic.com, SpeedInfo detectors
NOVA	**K**	10	DTR: I-495 to Rt.28 (non VDOT) Rt.7: I-495 to Rt.28 FfxCo. Pkwy (Rt.7100) Rt.7 to DTR Rt.28: Rt. 7 to DTR	1A: HOV	100,000	Y	Y (2)	HOV Lanes	SSP	HOV Lanes are not grade separated, so lane by lane VSO information is necessary.
NOVA	**H1**	16	I-66: Rt. 50 to Bull Run	1A: HOV	135,000	Y	Y	HOV Lanes, Shoulder Lanes, Traveler Information	SSP	HOV Lanes are not grade separated, so lane by lane VSO information is required
NOVA	**H2**	16	I-66: Bull Run to Rt. 15	1A: HOV	85,000	Y	N	HOV Lanes	SSP	HOV Lanes are not grade separated, so lane by lane VSO information is required. Future detection from I-66/Linton Hall Project.
FRED	**D**	5	I-95 & Rt 1 in Stafford County	1C: Tier 2	140,000	Y	Y (3)			I-395/I-95 HOT Lanes: expected operational in 2015
NOVA	**W**	8	Rt.50: I-66 to Rt.15	1C: Tier 2	120,000	N	Y (2)			
NOVA	**P**	9	Rt.3000: Rt.28/234 to I-95 Rt.28: DTR to I-66 Rt.28: I-66 to Rt.234/3000	1C: Tier 2	100,000	Y	Y (2)			
NOVA	**O**	11	Rt.7100: DTR to I-95 Rt. 123: Rt. 7100 to I-95	1C: Tier 2	140,000	N	Y (4)			

DISTRICT	BUNDLE	BASE PRIORITY RANKING	BUNDLE DESCRIPTION	HIGH-LEVEL REQUIREMENT PROFILE***	AVERAGE ANNUAL DAILY TRAFFIC (AADT)	CONTROL ACCESS (Yes/No)	EXISTING DETECTORS (Yes/No)**	APPLICATION	SSP	Opportunity / Consideration
FRED	**E**	13	I-95 & Rt 1 in Spotsylvania County Rt.208 in Spotsylvania County	1C: Tier 2	100,000	Y	Y (3)			
NOVA	**Z**	14	Rt.193: from Rt. 7 to Rt.90005 Rt.123: from Rt. 267 to 90005	1C: Tier 2	80,000	N	Y (1)			
NOVA	**I**	15	Rt.215: Rt.29 to Rt.28 Rt.234: I-66 to I-95 Rt.28: from Rt.234 to Prince William Co.	1C: Tier 2	40,000	N	Y (2)			
NOVA	**Y**	17	Rt.244: Rt.27 to Rt.236 Rt.620: Rt.236 to Rt.7100	1C: Tier 2	80,000	N	N	N/A		
NOVA	**Q**	18	Rt.15: NRO boundary to Rt. 29 Rt.234: Rt.15 to Rt.29	1C: Tier 2	40,000	N	Y (3)			
NOVA	**M**	19	Rt. 7: Rt. 15 Leesburg to NRO boundary Rt. 9: Rt. 7 to NRO boundary Rt. 287: Rt. 9 to Rt. 7	1C: Tier 2	60,000	N	Y (4)			
FRED	**R**	21	Rt. 218 Rt. 3: Rt. 20 to I-95 Rt. 3: Rt.17 to King George boundary Rt. 301: Rt. 3 to King George boundary	1C: Tier 2	60,000	N	N	N/A		
NOVA	**L**	22	DTR & Dulles Greenway: Rt.28 to Rt. 15 Leesburg (Non VDOT) Rt.7: Rt.28 to Rt.15 Rt.15: Leesburg & Rt.7 zone	1C: Tier 2	60,000	Y	N	N/A		
CULP	**J ***	25	I-66 in Fauquier County	1C: Tier 2	40,000	Y	Y (3)			Likely to be moved up to the priority order.
NOVA	**X**	26	Rt.236: Rt. 1 to Rt. 50/29 Rt.7: Rt.1 to I-395	1C: Tier 2	80,000	N	N	N/A		
FRED	**AA**	N/A	I-95 & Rt 1 in Caroline County	1C: Tier 2	80,000	Y	N			
STAUNTO N	**AB**	N/A	I-66 in Warren County	1C: Tier 2	37,000	Y	N			
CULP	**T**	16	Rt.15: Rt.29 to Rt.3 Rt.29: Rt.15 to Rt.215	1C: Tier 2	60,000	N	Y (8)			
CULP	**U**	20	Rt.17 & Rt.28 in Fauquier County	1C: Tier 2	40,000	N	Y (4)			
CULP	**S**	23	Rt.3: Rt.20 to Rt.29 Rt.29: Rt.3 to Madison County	1C: Tier 2	40,000	N	Y (2)			Likely to change the priority order.
CULP	**V**	24	Rt.211: Rt.29 to Rappahannock County	1C: Tier 2	40,000	N	Y (1)			

* J's priority ranking was moved to top of Culpeper post scoring. Reason: OSD's priority, OSD's comment on addressing interstate first, & OSD's desire to make this corridor as an ITS model corridor

****** The number in parentheses indicates the number of active Continuous Count Station detectors.

*** Non-freeway routes within the bundles require profile 1C: Non-HOV Tier 2

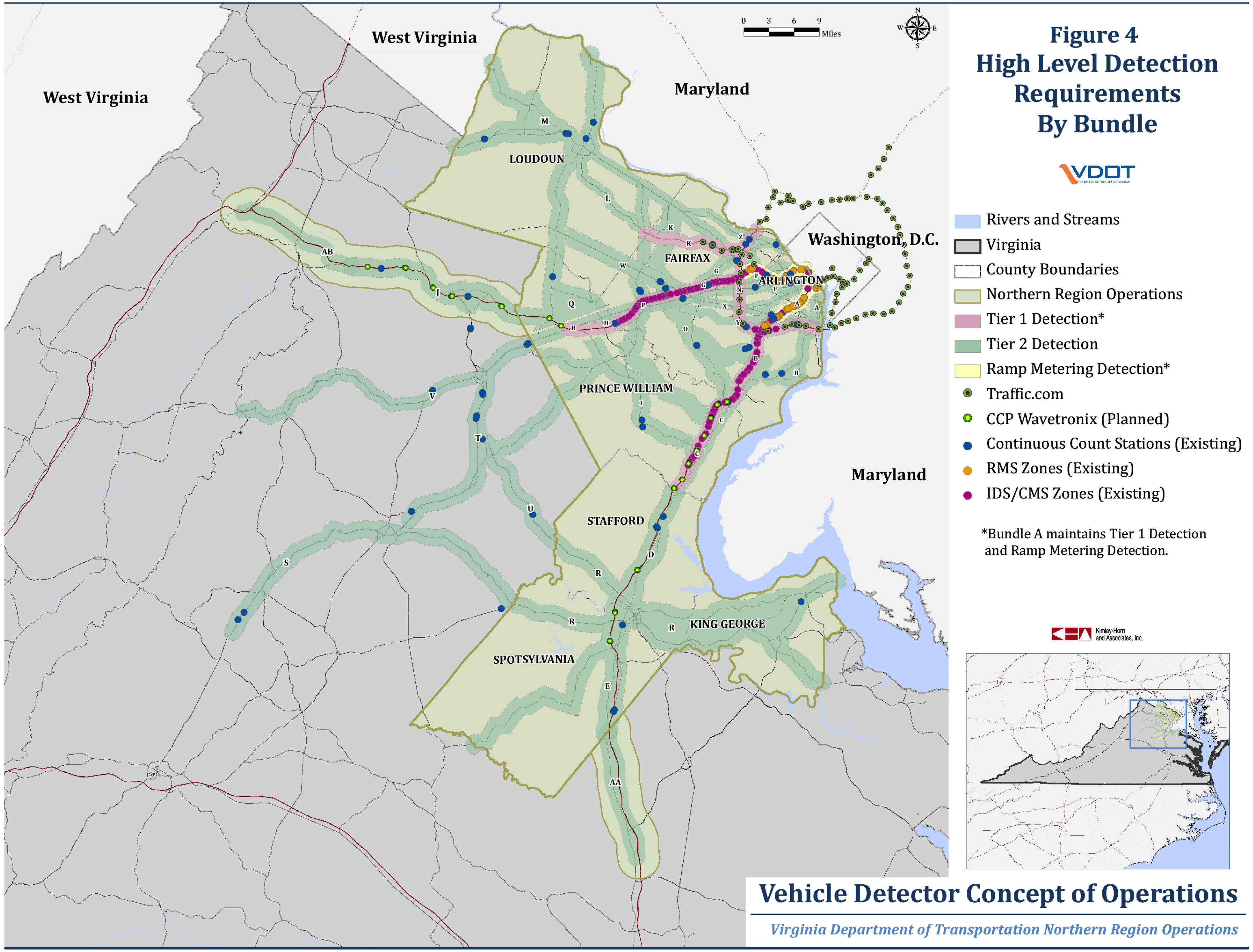

Figure 4. High-Level Detection Requirements by Bundle

3.4 Device Spacing and Placement Considerations

3.4.1 Link and Section Definitions

Detector spacing and placement are driven by the high-level requirements. Those requirements are expressed in terms of profiles, which are detailed in **Table 5**. In order to understand the spacing requirements, we define zones, stations, links and sections as follows:

- **Zone (or lane-by-lane):** Represents the actual spot zone of coverage, e.g. lane.
- **Station:** Represents the aggregation of all equivalent lanes with the same function and same direction, i.e., HOV and GP lane groups at a location would be different stations.
- **Link:** Links are defined as sections of contiguous road with the same cross section, lane use type and merging/weaving behavior. For example, approaching an interchange, a link would be defined as the distance from the beginning of the deceleration or exit lane to the end of the acceleration lane or on ramp. At the end of the acceleration lane a new link would start.
- **Section:** A collection of contiguous links, such as between major interchanges.
- **Freeway:** A collection of contiguous sections.

These are shown graphically in **Figure 5**.

Table 5. High-Level Requirements Profiles

	Profile 1: Real-Time/Operations Data		
	1A: Tier 1	1B: Tier 2	1C: Ramp Metering
Element	Speed, Volume, Occupancy	Speed, Travel Time	Speed, Volume, Occupancy
Temporal Resolution	1 minute	1 minute	1 minute
Spatial Resolution	Link Level, Lane By Lane	Section Level	Link Level, Stream[2,3]
Speed Accuracy[1]	20%	20%	20%
Volume Accuracy[1]	10%	N/A	10%
Availability	99.9%[4]	99.9%[4]	99.9%[4]
Point vs. Probe	Point	Point or Probe	Point

Notes:

1. Accuracy expressed as mean absolute percent error (MAPE).
2. For stream-level resolution, lane-by-lane measurement is not needed.
3. Also mainline detection either immediately upstream or downstream of metered ramp, depending on the requirements of metering algorithm, plus stop bar passage and presence, and queue spillback detection.
4. Approximately 10 hours down time per year.

	Profile 2: Off-Line Operations Analysis/Performance Measures		
	2A: Tier 1	2B: Tier 2	2C: Ramp Metering
Element	Speed, Volume, Occupancy	Speed, Travel Time	Speed, Volume, Occupancy
Temporal Resolution	5 minute	5 minute	5 minute
Spatial Resolution	Link Level, Lane By Lane	Section Level	Link Level, Stream[2,3]
Speed Accuracy[1]	20%	20%	20%
Volume Accuracy[1]	10%	N/A	10%
Availability	99.9%[4]	99.9%[4]	99.9%[4]
Point vs Probe	Point	Point or Probe	Point

Notes:

1. Accuracy expressed as mean absolute percent error (MAPE).
2. For stream-level resolution, lane-by-lane measurement is not needed.
3. Also mainline detection either immediately upstream or downstream of metered ramp, depending on the requirements of metering algorithm, plus stop bar passage and presence, and queue spillback detection.
4. Approximately 10 hours down time per year.

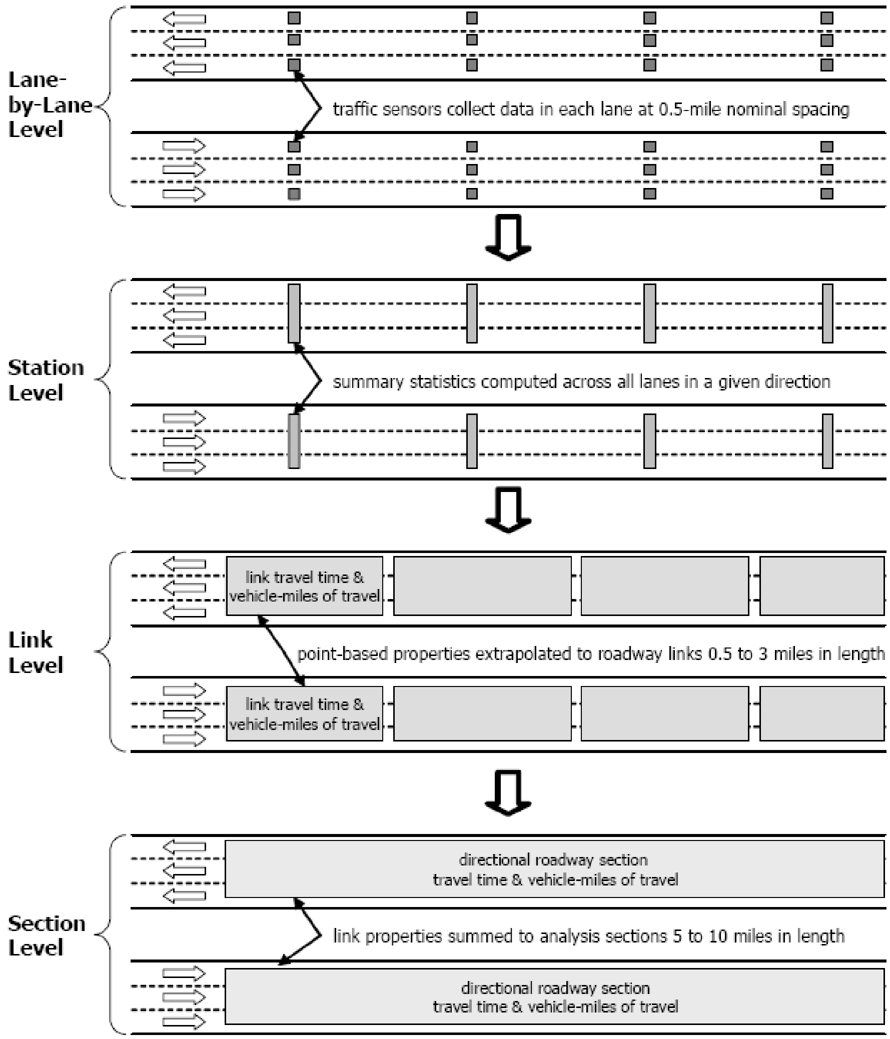

Figure 5. Aggregating Traffic Detector Data to Different Geographic Sites

Source: Turner, S.R., Margiotta, T., Lomax. Monitoring Urban Freeways in 2003. Current Conditions and Trends from Archived Operations Data. Report No. FHWA-HOP-05-018, Accessed at http://mobility.tamu.edu/mmp/FHWA-HOP-05-018/, December 2004

NRO's Freeway Engineering group has narrowed the above link definition to be no longer than one mile. **Figure 6** shows how the limits of short links are determined solely by changes in the roadway geometry. **Figure 7** shows how longer homogenous roadway sections would have links capped at one-mile lengths.

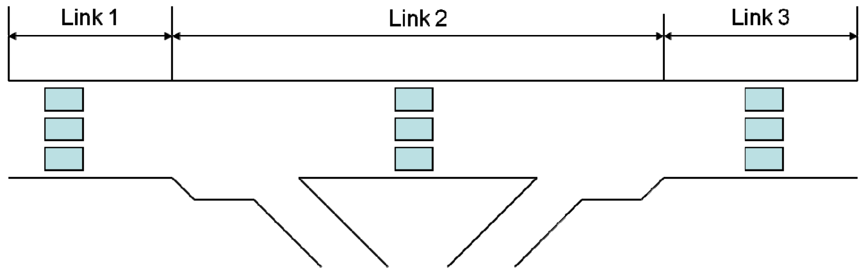

Figure 6. Short links whose limits are determined by geometry

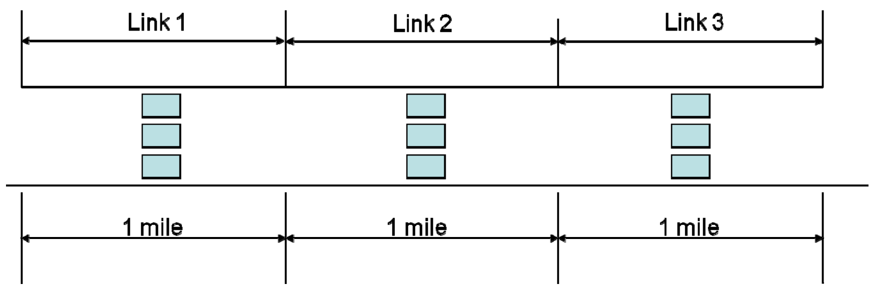

Figure 7. Links on longer homogenous sections whose lengths are capped at 1 mile

It is recommended that in the future VDOT consider migrating to the use of "TMC Codes," the segmentation used as a de facto standard by the digital mapping duopoly: Tele Atlas and Navteq. TMC Codes define links based on homogenous geometry, much like what has been described above. They are used by content providers such as Inrix to locate points of interest on digital maps found online or in navigation systems. As the private sector grows in its influence in the provision of traffic data, it is likely these TMC Codes will become a widely recognized national standard for both the public and private sectors. In the I-95 Corridor Coalition Contract for probe vehicle data, Inrix will provide the TMC Code link definitions to Coalition member states.

Certain locations require a detector spacing of one-per-link. However, others only require a spacing of one detector per section (i.e., one per interchange). For sections with ramp meters, the required detector spacing is one per link, but instead of placing those detectors at the link mid-points, they are required to be in the vicinity of the metered on-ramps. **Figure 8** depicts the detection zones for ramp meters per the NTCIP standard. It should be noted that not all of these detectors are needed to run ramp metering. In particular, depending on the metering algorithm chosen by VDOT, the mainline detection (L1-L8 and T1-T8) will either be upstream or downstream of the ramp, but not both.

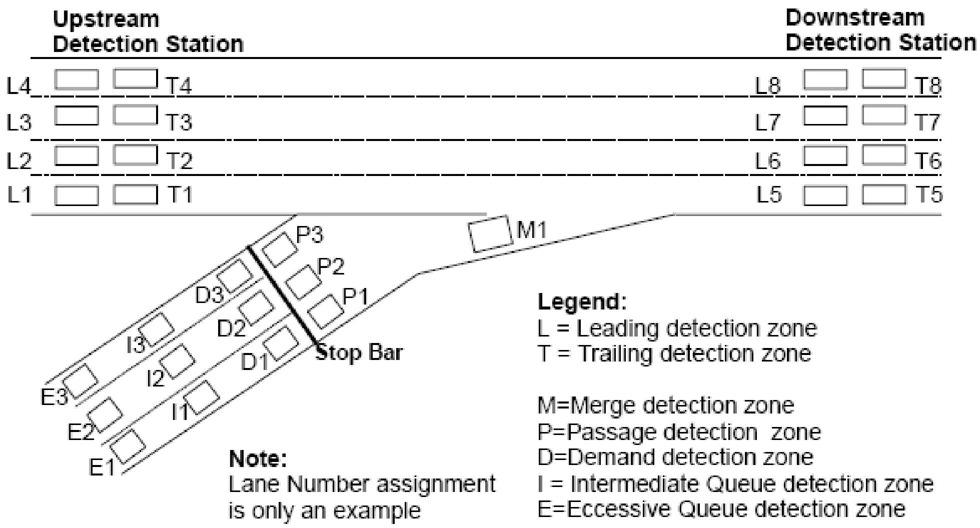

Figure 8. Detection zones for ramp metering

Source: NTCIP 1207 Object Definitions for Ramp Meter Control Units

3.5 Cost Considerations

This detector master plan includes over 260 centerline miles of freeway and over 618 miles of arterial streets. Note, however, that 140 of those arterial miles are now part of the NWRO rather than the NRO. This is shown in **Table 6**. Mileage and other data by bundle is shown in **Table 7**.

Table 6. NRO Bundles Mileage Breakdown

	Freeway Miles	Arterial Miles
Core Network	123.6	94.2
Extended	137.2	127.4
Future	0.0	396.9
Total	**260.8**	**618.5**

Table 7. Estimates of Detector Quantities

DISTRICT	BUNDLE	BASE PRIORITY RANKING	BUNDLE DESCRIPTION	FREEWAY MILES	AVERAGE INTERCHANGE SPACING (FREEWAY)	NUMBER OF SEGMENTS	AVERAGE DETECTOR SPACING	ARTERIAL MILES
NOVA	**B**	1	I-95: I-495 to Rt.123 Rt.1: I-495 to Rt.123 Rt. 235	9.9	1.7	**15**	0.2	16.0
NOVA	**N1**	7	I-495: American Legion Bridge to Rt. 267	3.2	1.1	3	0.2	N/A
NOVA	**N2**	7	I-495: Rt. 267 to I-395	12.1	1.5	8	0.6	N/A
NOVA	**A**	2	I-395: DC Line to I-495 Rt. 110: Rt. 1 to I-66 GW Pkwy: DC Line to I-495 (non VDOT)	9.6	0.5	**19**	0.1	3.5
NOVA	**F**	3	I-66: DC Line to I-495 Rt.267: I-66 to I-495 Rt. 29: DC Line to I-495 Rt. 50: DC Line to I-495	9.8	1.2	8	0.2	18.6
NOVA	**N3**	7	I-95/I-495: I-395 to Woodrow Wilson Bridge	7.5	0.9	8	0.4	N/A
NOVA	**H1**	16	I-66: Rt. 50 to Bull Run	5.8	1.5	4	0.1	N/A
NOVA	**G**	4	I-66: I-495 to Rt. 50 Rt.29: I-495 to Rt. 50 Rt.50: I-495 to I-66 Rt.123: Rt. 7 to Rt.236 Rt.243: 123 to Rt. 29	7.1	2.4	3	0.2	19.6
NOVA	**C**	6	I-95 & Rt 1 in Prince William County	12.6	2.5	**14**	0.3	11.7
NOVA	**K**	10	DTR: I-495 to Rt.28 (non VDOT) Rt.7: I-495 to Rt.28 FfxCo. Pkwy (Rt.7100) Rt.7 to DTR Rt.28: Rt. 7 to DTR	12.5	1.4	9	2.1	24.8
NOVA	**H2**	16	I-66: Bull Run to Rt. 15	11.5	3.8	3	N/A	N/A
NOVA	**O**	11	Rt.7100: DTR to I-95 Rt. 123: Rt. 7100 to I-95	N/A	N/A	N/A	0.1	33.8
FRED	**D**	5	I-95 & Rt 1 in Stafford County	14.5	3.6	4	7.3	15.7
NOVA	**W**	8	Rt.50: I-66 to Rt.15	N/A	N/A			16.5
FRED	**E**	13	I-95 & Rt 1 in Spotsylvania County Rt.208 in Spotsylvania County	15.0	5.0	3	7.5	13.7
NOVA	**P**	9	Rt.3000: Rt.28/234 to I-95 Rt.28: DTR to I-66 Rt.28: I-66 to Rt.234/3000	16.0	1.5	11	8.0	14.2
FRED	**AA**	N/A	I-95 & Rt 1 in Caroline County	20.6	6.9	3	N/A	20.5
NOVA	**L**	22	DTR & Dulles Greenway: Rt.28 to Rt. 15 Leesburg (Non VDOT) Rt.7: Rt.28 to Rt.15 Rt.15: Leesburg & Rt.7 zone	13.2	1.9	7	N/A	13.0
CULP	**J ***	25	I-66 in Fauquier County	21.5	4.3	5	7.2	N/A
STAUNTON	**AB**	N/A	I-66 in Warren County	18.8	6.3	3	N/A	N/A

DISTRICT	BUNDLE	BASE PRIORITY RANKING	BUNDLE DESCRIPTION	FREEWAY MILES	AVERAGE INTERCHANGE SPACING (FREEWAY)	NUMBER OF SEGMENTS	AVERAGE DETECTOR SPACING	ARTERIAL MILES
NOVA	**Z**	14	Rt.193: from Rt. 7 to Rt.90005 Rt.123: from Rt. 267 to 90005	N/A	N/A	N/A	0.1	15.9
NOVA	**Y**	17	Rt.244: Rt.27 to Rt.236 Rt.620: Rt.236 to Rt.7100	N/A	N/A	N/A	N/A	18.3
NOVA	**X**	26	Rt.236: Rt. 1 to Rt. 50/29 Rt.7: Rt.1 to I-395	N/A	N/A	N/A	N/A	18.7
NOVA	**M**	19	Rt. 7: Rt. 15 Leesburg to NRO boundary Rt. 9: Rt. 7 to NRO boundary Rt. 287: Rt. 9 to Rt. 7	N/A	N/A	N/A	0.1	36.8
FRED	**R**	21	Rt. 218 Rt. 3: Rt. 20 to I-95 Rt. 3: Rt.17 to King George boundary Rt. 301: Rt. 3 to King George boundary	N/A	N/A	N/A	N/A	82.2
NOVA	**I**	15	Rt.215: Rt.29 to Rt.28 Rt.234: I-66 to I-95 Rt.28: from Rt.234 to Prince William Co.	N/A	N/A	N/A	0.1	38.3
NOVA	**Q**	18	Rt.15: NRO boundary to Rt. 29 Rt.234: Rt.15 to Rt.29	N/A	N/A	N/A	0.1	46.0
CULP	**T**	16	Rt.15: Rt.29 to Rt.3 Rt.29: Rt.15 to Rt.215	N/A	N/A	N/A	0.2	33.1
CULP	**U**	20	Rt.17 & Rt.28 in Fauquier County	N/A	N/A	N/A	0.1	31.8
CULP	**V**	24	Rt.211: Rt.29 to Rappahannock County	N/A	N/A	N/A	0.0	31.4
CULP	**S**	23	Rt.3: Rt.20 to Rt.29 Rt.29: Rt.3 to Madison County	N/A	N/A	N/A	0.0	44.4

Cost estimates for various market leading point detectors were obtained by NRO from different regional vendors and a summary is given in **Table 8**. Given these data, a simplified table of probable cost estimates for detection is given in **Table 9**. These assume costs of $20,000 per detector for new freeway installations and a $10,000 cost of replacing a detector where a cabinet and communications already exist. While different emerging technologies may provide more attractive pricing, **Table 9** provides a baseline for comparison since it represents a known and proven commodity.

Table 8. Cost Estimates from Regional Vendors for Point Detectors

Detector Type	Layout	Capital Cost	Life (yrs)	Monthly Maintenance Cost	10-year Maintenance Cost
SmartSensor™, digital radar	6 lanes	$9,450	12.5	$63	$7,560
RTMS™, radar	6 lanes	$8,950	12.5	$60	$7,160
Sensys Networks™, magnetometer	6 lanes	$8,400	10	$70	$8,400
Inductive Loop	6 lanes	$18,000	5	$300	$36,000

Note: Costs do not include communications with central system

Table 9. Simplified Cost Estimates and Expected Life Cycle of Point Detectors

	Installation Cost	Annual Maintenance	Annual Cost (10-yr life)	Ten-year Cost (10-yr life)
Replacement	$10,000	$750/yr	$1750	$17,500
New Site	$20,000	$750/yr	$2750	$27,500

Note: Replacement would apply to Bundles A, B, C, F, G, H1 (I-66, I-395, I-95)

Tier 2 requirements, where lane-by-lane speed, volume and occupancy are not needed, can potentially be met from probe vehicle sources pending sufficient data quality, timeliness and availability. For probe data, a cost estimate of $750 per mile is derived from the I-95 Corridor Coalition contract for Inrix probe data. This contract vehicle is available to VDOT for contractually predetermined routes (shown in **Figure 3**), which includes some of the higher priority arterial streets. The geographic coverage area can also be expanded to other routes through the contract. Regardless of whether this data source is used, this contract price sets the market rate for any competitors over the life of the I-95 contract and therefore represents a reasonable cost estimate for probe data. It must be noted that it is not known at this time whether this data meets the high-level requirements defined for detector data in terms of temporal and spatial resolution, accuracy or availability.

The cost estimates above do not include communications costs. For low bandwidth devices such as vehicle detectors, it makes little sense to build out fiber or another type of wire-line communications plant unless that expansion is being driven by video or a high density of different devices (e.g., DMS, RWIS, etc.). Costs for devices not on the fiber network would add approximately $75/month for cellular service, or another $900 per year per agency owned device.

4 FUTURE CONSIDERATIONS

This plan seeks to identify detection requirements by location according to the traffic data requirements for NRO freeway and arterial segments. These requirements represent an incremental build-out over time, according to which segments have been assigned a higher priority, considering a 20-year time horizon. That being said, it is highly probable that twenty years from now, fixed infrastructure-based detection will be reserved only for specific applications, such as those where highly accurate traffic volumes are needed.

For this reason, it is recommended that aggressive expansion of agency-owned and maintained fixed infrastructure detection not be pursued to meet Tier 2 profile requirements. Rather, it is recommended that fixed infrastructure high resolution (e.g., lane-by-lane speed, volume and occupancy) detection be reserved for meeting Tier 1 profile requirements (as required for ramp meters, HOV lanes, controlled/shoulder lanes, etc.). Elsewhere, lower investment alternatives should be pursued. This will almost certainly involve the private sector. In the near term, that may be SpeedInfo, Inrix or some combination of both. In the longer term, that may also include cell phone tracking, private GPS navigation devices or VII, depending on where the market leads. It should be noted that none of these involves unproven technologies, with the exception of some of the standards envisioned to support VII. However, the market for the provision of traffic data by the private sector is rapidly evolving with new business models and business-to-business relationships. That being said, the private sector has yet to prove it can be viable and sustainable long-term.

5 HIGH-LEVEL SUMMARY OF RECOMMENDATIONS

Freeways

- Focus on key applications: travel time traveler information, daily performance measurement. Continue work with universities to create performance measures reports that NRO can incorporate into business processes.
- Deploy any additional detection needed for traffic-responsive ramp metering, requirements to be dictated by the chosen metering algorithm.
- Add density as needed to achieve link-level coverage (one sensor per interchange), lane-by-lane volume, speed, occupancy to meet Tier 1 requirements.
- Take full advantage of opportunities (Traffic.com, SpeedInfo, HOT lanes, CCP) to add sensor coverage/density without additional required NRO maintenance.
- Use temporary detection (i.e., SpeedInfo) where new deployments are anticipated (e.g., HOT Lanes on I-495, I-395/95).

- Expand on key corridors (I-66, I-95) once traveler information, performance measurement programs are at goals for existing coverage areas.
- Expand on key corridors to capture HOV lane utilization (I-66 to Rt. 29) for performance measurement.

Arterials

- Identify key off-ramp locations for sensors to support integrated corridor management in concert with cameras
- Pursue probe vehicle data collection for arterials, first for performance measurement and then for real-time traveler information. Explore feasibility of private data (e.g., Inrix) for select arterial corridors. Explore feasibility emerging technologies to track vehicles (e.g., vehicle re-identification using loops[1], tracking of Bluetooth device signatures[2]).
- Explore ways to utilize MIST stop bar or system detector data to capture arterial/intersection level of service and performance measures

Future Applications

- Continue to explore new traffic management strategies and deploy detection as needed for those specific strategies (e.g., variable speed limits, mainline queue alerts)

---

[1] Coifman, B., Ergueta, E., *Improved Vehicle Reidentification and Travel Time Measurement on Congested Freeways*, ASCE Journal of Transportation Engineering, Vol 129, No 5, 2003, pp 475-483.
[2] Jason S. Wasson, P.E., James R. Sturdevant, P.E. and Darcy M. Bullock, P.E., *Real-Time Travel Time Estimates Using Media Access Control Address Matching*, ITE Journal, Vol. 78 (6), June 2008.

1 Introduction

A Validation Plan provides a guide for evaluating a deployed ITS system to determine if it has met its goals. The Validation Plan lists criteria for judging whether or not the ITS system meets the user needs and objectives defined in the Concept of Operations. This Validation Plan addresses the needs and objectives defined in the Vehicle Detector Concept of Operations for the Virginia Department of Transportation (VDOT) Northern Region Operations (NRO). It is intended to be used in validating the future Vehicle Detector System in Northern Virginia against the VDOT NRO Vehicle Detector Concept of Operations and the High Level Requirements for VDOT NRO Detectors.

The validation plan is divided into "stakeholder groups" corresponding to Section 4: Operational Needs of the VDOT NRO Vehicle Detector Concept of Operations. These categories are VDOT NRO Traffic Management Center Operators, VDOT NRO Traffic Management Center Supervisors, VDOT NRO Freeway Engineers, VDOT NRO Traffic Signal Operations Engineers, VDOT Continuous Count Program, VDOT NRO Maintenance Division, VDOT NRO Traffic Engineering, and VDOT NRO Transportation Planning. For each operational need, the Validation Plan asks if the deployed system meets that need.

2 VDOT NRO Traffic Management Center Operators

1.1. Monitor Congestion Levels

Does the detection system populate a Congestion Map showing current traffic conditions compared to representative historical conditions?

1.2. Integrated Corridor Management

Is the detection system able to effectively compare conditions on bundled parallel routes and guide diversion management decisions?

Are there any critical gaps in the detection system's coverage of freeways and arterials for each deployed roadway bundle?

1.3. Improve Operator Efficiency

Is the detection system able to effectively alert TMC Operators to abnormal conditions that require attention in a way that is helpful and not a distraction?

1.4. Operate Ramp Meters

Does the detection system accurately capture conditions at merge areas on freeways?

1.5. Ramp Meter Queue Alerts

Does the detection system reliably detect when a ramp queue extends onto arterials?

1.6. Operate HOV Facilities

Does the detection system help TMC Operators determine when to override regular HOV hours and open HOV lanes to all traffic?

1.7. Operate Reversible Flow Facilities

Does the detection system help TMC Operators determine when to reverse the direction of flow on reversible flow facilities?

1.8. Wrong-Way Traffic Alerts

Can the detection system alert TMC Operators to wrong-way traffic in reversible lanes?

1.9. Operate Controlled (Shoulder) Lanes

Does the detection system help TMC Operators determine when to open, or close, controlled lanes to traffic?

1.10. Provide Travel Times

Does the detection system generate accurate real-time travel times between certain points of interest to post on DMS message boards, 511, and other dissemination tools to alert travelers to delays?

1.11. Actively Manage Speed Limits

Can the detector system be used to monitor conditions at weave areas, merge areas, bottlenecks, and diversion areas for freeways as required to support using variable speed limits to improve traffic flow?

1.12. Provide Queue Warning

Can the detector system be used in an automated system that will warn drivers of stopped vehicles ahead?

Is the spatial frequency of the sensors providing sufficient notification time for TMC operators to provide an effective response?

1.13. Manage Parking

Does the detection system accurately return the number of occupied parking spaces at park and ride lots to alert drivers as to whether the lot is full?

Is the information supplied to the ATMS to allow the operator to quickly update relevant freeway DMS?

1.14. Monitor/Facilitate Evacuation

Is the detector system able to effectively compare conditions on bundled parallel routes and guide diversion management decisions?

Can the detector system be used to monitor and manage traffic due to unscheduled events?

1.15. Provide Traveler Information

Can the detector system be used to gather reliable real-time traffic flow information for the 511 system?

3 VDOT NRO Freeway Engineers

1.16. Plan for Maintenance or Construction

Can the detector system be used to provide historical data to help determine allowable hours for maintenance or construction?

1.17. Manage Major Roadwork

Can the detector system be used to monitor long-term construction?

1.18. Evaluate Effectiveness of Traffic Control

Can the detection system help evaluate the effectiveness of traffic management and incident management strategies?

1.19. Evaluating HOV Lanes Hours of Operation

Does the detection system archive lane usage data on freeways to help determine HOV hours of operation?

1.20. Evaluating Controlled (Shoulder) Lanes Hours of Operation

Does the detection system collect lane usage data on freeways to help determine when to open controlled lanes to traffic?

1.21. Measure HOV Throughput

Does the detector system coverage sufficiently monitor conditions on express lanes, such as High Occupancy Vehicle (HOV) Lanes?

1.22. Measure HOV Speeds versus General Purpose (GP) Speeds

Is the detector system able to effectively compare conditions on HOV Lanes and GP Lanes?

1.23. Evaluate Reversible Lane Operations

Does the detection system collect speed data on freeways to help Freeway Engineers set policy with respect to when to reverse the direction of flow on reversible flow facilities?

1.24. Monitor Ramp Meter Operations

Can the detection system be used to monitor conditions at merge areas on freeways to set policy with respect to ramp metering rates and control modes (e.g., traffic-responsive vs. time-of-day)?

1.25. Measure Ramp Volumes

Can the detector system measure ramp volumes to help facilitate potential policy changes to metering rates?

1.26. Detect Mainline Traffic Flows

Can the detector system detect mainline traffic flows to adjust standard metering rates?

1.27. Queue Alerts

Can the detector system collect and archive data to assess where, when, and how often ramp meter queues spillback onto arterial streets?

Are queue detectors appropriately located to provide the desired data quality?

1.28. Evaluate Effects of Road Work

Can the detector system be used to monitor long-term construction?

Can the detector system be used to monitor temporary lane closures?

1.29. Monitor Lane Control

Does the detection system collect speed data on freeways to help Freeway Engineers be able to determine standard hours to open controlled lanes to traffic?

4 VDOT NRO Traffic Signal Operations Engineers

1.30. Integrated Corridor Management

Is the detector system able to effectively compare conditions on bundled parallel routes and guide diversion management and signal timing decisions?

1.31. Detect Volumes in Real-Time

Does the detector system detect volumes on arterials (15 minute intervals) and guide decisions to switch timing plans in real-time?

1.32. Monitor Turning Movements

Does the detector system return the volume of vehicles on key turning movements on detour routes in real-time?

1.33. Optimize Signal Phasing and Timing

Can the detector system be used to archive data to optimize the signal plan for a corridor?

5 VDOT Continuous Count Program

1.34. Collect Complete Data

Does the detector system collect continuous traffic volume data for every lane between each freeway interchange?

Is the density of detectors providing adequate data where sensors are deployed?

1.35. Collect Reliable Data

Are detectors as reliable (maintaining sufficient up-time) as specified?

1.36. Collect Data Daily

Does the detector system collect and upload daily data for no greater than 15 minute time intervals?

1.37. Vehicle Classification

Does the detector system collect vehicle classification data at a sample of locations?

Is the density of detectors providing adequate data where sensors are deployed?

6 VDOT NRO Maintenance Division

1.38. Minimize Maintenance Work Orders

Do the voltage smoothing Uninterruptable Power Supply (UPS) backup power supplies provide sufficient backup times for the connected devices?

Are electrical/communication lead-in cables properly protecting devices against lightning and transient electrical surges?

Are independent power supplies preventing other ITS equipment from adversely affecting the detector system and vice versa?

Are sealed conduits and junction boxes protecting power and communication cables against line breaks?

Are field device locations preventing vandalism?

Are device foundations preventing erosion and/or undermining?

Are components maintaining sufficient reliable up-time as specified?

Are components robust and weatherproofed as specified?

Are components reaching their life expectancy?

1.39. Troubleshoot Detector Problems Remotely

Can maintenance personnel reset detector devices remotely?

Can maintenance personnel test detector devices remotely?

1.40. Perform Routine Maintenance and Repairs Quickly

Do maintenance personnel find it simple to remove, replace, and service detector equipment?

Are all detection devices of the same model for easy replacement of parts?

Are device and part replacements readily available for existing installations?

Are mean-time to repair estimates being achieved?

1.41. Safe Conditions

Is there a stable parking space on the shoulder at all detector device locations?

Can maintenance personnel access detector equipment in a safe manner?

Can maintenance personnel access detector equipment without requiring lane closures or encroaching on a travel lane?

Are devices never located in a median?

Is all detector equipment protected from vehicle impact by guardrail or placement away from edge of pavement?

1.42. Inventory/Lifecycle Replacement

Are all devices and components bar coded in accordance with the NRO Inventory Barcode Requirements?

Does the method of identifying detectors help to systematically describe and locate them?

Does the Inventory and Maintenance Management System (IMMS) track all detector devices and components through logged descriptors and identifiers, including IP number?

Is all field equipment logged in the IMMS at the time of deployment?

Are replacement devices and equipment stocks logged in the IMMS?

Do maintenance personnel update the IMMS after performing maintenance?

Do maintenance personnel update the IMMS after replacing bar coded equipment?

7 VDOT NRO Traffic Engineering

The needs for Traffic Engineering staff are largely those already listed under Freeway Engineers. Additional needs for Traffic Engineering staff are for spot studies for safety, signal warrants, etc. However, these studies do not require continuous data collection and by their nature, their locations are unpredictable.

8 VDOT NoVA, Fredericksburg, and Culpeper District Transportation Planning

1.43. Perform Accurate Forecasting

Can the detector system archive high quality historic flow data on freeways and arterials with which to set in place future policies and long-term planning?

Does the detector system reduce the need for outsourcing data collection studies?

1.44. Collect Origin/Destination Data

Can the detector system collect high quality origin and destination trip data with which to help set in place future policies and planning?

Does the detector system reduce the need for outsourcing data collection studies?

1.45. Study Validation

Can the detector system archive high quality historic flow data to be used to verify that its studies are accurate in order to reinforce its decisions regarding policies and planning?

1.46. Monitor Park and Ride Lots

Does the detection system consistently and accurately return the number of occupied parking spaces at park and ride lots?

Does the detector system collect data that can be used to measure utilization trends?

9 Private Sector

Are private sector detectors providing speed information that can be used to determine traveler information?

10 Program Managers

Are performance measures being provided to program managers for use in strategically managing investments?

11 Regional Media Outlets

Are regional media outlets getting accurate incident and traffic information to disseminate to the traveling public?