A Connected Vehicle–Enabled Virtual Dynamic Message Sign System Demonstration and Evaluation on the Virginia Connected Vehicle Test Bed

CVI UTC

CONNECTED VEHICLE/INFRASTRUCTURE UNIVERSITY TRANSPORTATION CENTER (CVI-UTC)

MORGAN STATE UNIVERSITY
VirginiaTech Transportation Institute
UNIVERSITY of VIRGINIA
VDOT

A Connected Vehicle–Enabled Virtual Dynamic Message Sign System Demonstration and Evaluation on the Virginia Connected Vehicle Test Bed

Prepared for the Research and Innovative Technology Administration (RITA);
U.S. Department of Transportation (US DOT)

Grant Project Title:
Advanced Operations Focused on Connected Vehicles/Infrastructure (CVI-UTC)

Consortium Members:
Virginia Tech Transportation Institute (VTTI),
University of Virginia (UVA) Center for Transportation Studies,
and Morgan State University (MSU).

Program Director:
Dr. Thomas Dingus
Director Virginia Tech Transportation Institute
Director National Surface Transportation Safety Center for Excellence
Newport News Shipbuilding Professor of Engineering at Virginia Tech
tdingus@vtti.vt.edu
(540) 231 – 1501

Report Authors:
Hyungjun Park, PhD
Senior Scientist, University of Virginia Center for Transportation Studies
hpark@email.virginia.edu
(434) 924-1651

Simona Babiceanu
IT Lab Manager, Transportation Systems Engineer, Department of Civil and Environmental Engineering
seb4v@virginia.edu

Robert Kluger
Graduate Research Assistant
rmk7su@virginia.edu

Brian Smith, PhD, PE
Director, University of Virginia Center for Transportation Studies
Professor and Chair, Department of Civil and Environmental Engineering
briansmith@virginia.edu

David Recht
Graduate Research Assistant

DUNS: 0031370150000 EIN: 54-6001805

Grant Funding Period: January 2012 – July 2016
Final Research Reports
March 15, 2016

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

Connected Vehicles/Infrastructure UTC

The mission statement of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) is to conduct research that will advance surface transportation through the application of innovative research and using connected-vehicle and infrastructure technologies to improve safety, state of good repair, economic competitiveness, livable communities, and environmental sustainability.

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

Abstract

Dynamic message signs (DMSs) are widely used to deliver traveler information. While these have proven to be effective, key limitations exist: (1) the locations of DMSs are fixed, (2) reading a DMS message is distracting to drivers, and (3) installation and maintenance of DMSs is expensive. To address these limitations, a smartphone-based virtual DMS (VDMS) application was developed in the first round of Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) projects. This application used smartphones to provide audible "reading" of DMS messages to drivers.

This project built upon previous work to develop a more advanced, second generation of the VDMS system, that is fully integrated in the Dedicated Short Range Communications (DSRC) environment of the Virginia Connected Vehicle Test Bed. The highlights of the enhanced VDMS system include (1) use of four of 40+ DSRC-based roadside equipment units (RSEs) on the Virginia Connected Vehicle Test Bed, and (2) software (VDMS Manager) that has the capability to virtually "build" new DMSs and to create modified and new messages for those DMSs.

To evaluate the VDMS system as an information dissemination tool to support advanced traffic management, operational testing (including three surveys, entrance, post-incident, and exit) was carried out with actual operators at the McConnell Public Safety and Traffic Operations Center. It was observed that operators preferred the VDMS system due to its capability of providing more detailed and customized messages at more appropriate locations for motorists.

Acknowledgments

This research was funded under Grant No. 0031370150000 by the Connected Vehicle Infrastructure University Transportation Center (CVI-UTC) program of the Research and Innovative Technology Administration of the U.S. Department of Transportation. The authors thank several individuals: Candice Gibson and her staff of the McConnell Public Safety and Traffic Operations Center (PSTOC) for their support and insights in the operational testing; the PSTOC operators for exercising operational testing and filling in the survey; Andy Peterson, Brian Leeson, and their staff of Virginia Tech Transportation Institute for developing the code for field equipment; Alona Green of Morgan State University and Brittany Hungate of the Department of Civil and Environmental Engineering at the University of Virginia for data collection and analysis.

Table of Contents

List of Figures

List of Tables

Introduction

Dynamic Message Signs (DMSs) have long served as one of the primary means that a Department of Transportation (DOT) has to deliver dynamic information to travelers. This is significant given that the delivery of dynamic information underpins the vast majority of advanced traffic management initiatives—for example, the majority of those strategies and systems identified as being of particular interest to the Virginia DOT (VDOT) in the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) Request for Proposal (RFP): active traffic management, work zone safety, routing advisories, traveler information, and incident management. As DOTs attempt to do more advanced traffic management, the severe limitations of traditional DMSs in terms of information content, distraction, and limited physical installations will hamper the effectiveness of these advanced strategies. Hence, there is a need to find a better way to deliver information to drivers.

In a just-completed CVI-UTC Round 1 study, the University of Virginia Center for Transportation Studies (UVA CTS) took two important steps in investigating ways that connected vehicles (CVs) can address the limitations of DMSs. First, given that the Virginia Connected Vehicle Test Bed was still in the development stage, UVA CTS developed a virtual DMS (VDMS) application that functioned purely on smartphones. This demonstrated the feasibility of a VDMS, and helped the team gain valuable experience in linking messages on existing DMSs to a CV application. Second, the UVA CTS team conducted extensive human subject testing of audible messages from VDMSs versus visual messages from traditional DMSs using a driving simulator. The results of this work proved that audible messages from VDMSs have the capacity to provide significantly more information than visual messages from traditional DMSs, and that audible messages were significantly less distracting than traditional visual messages. This work provided the foundation for the study proposed here to enhance the existing VDMS system, to fully integrate it in the Dedicated Short Range Communications (DSRC)-enabled environment of the Virginia Connected Vehicle Test Bed, and then to demonstrate and evaluate the system on the test bed.

To provide more specifics, highlights of the enhanced VDMS system developed in this research project included (1) use four of 40+ DSRC-based roadside equipment (RSE) units for communications, (2) a software application, VDMS Manager, that has the capability to virtually "build" (or create) new DMSs as opposed to being limited to the fixed locations of existing DMSs, and (3) functionality to provide expanded information on work zone safety and management, incident response and management, and routing advisories (particularly focusing on parallel routes within the test bed).

Goal and Objectives

The goal of this project was to develop, demonstrate, and evaluate a VDMS system on the Virginia Connected Vehicle Test Bed. Key objectives were as follows:

1. To develop a comprehensive VDMS system consisting of the VDMS Manager software application and the applications for the onboard equipment (OBE), data acquisition system (DAS), RSE, and remote servers;

2. To demonstrate the developed VDMS system on the Virginia Connected Vehicle Test Bed in Northern Virginia; and

3. To examine the feasibility of a VDMS system to support VDOT's advanced traffic management needs.

Virtual Dynamic Message System Concept

The purpose of the VDMS system is to provide a new, enhanced means of information delivery for the traveling public that makes use of DSRC technology available in CV environments. The software targets three improvements compared to information dissemination via physical DMSs:

- Posting more detailed and customized traveler information messages, reducing the limitations on the number of information units imposed by the physical constraints of the DMS assets;

- Creating virtual new DMSs at relevant locations as opposed to only being able to use the fixed geographic zones of existing DMS assets; and

- Using audio as a means of message delivery to motorists, as opposed to relying on the visual task of reading messages from the road signs.

Motorists using the VDMS system will be presented with the same messages posted by VDOT on physical DMSs and also with additional information that is not displayed on the physical DMS signs. This extra information could be of a varied nature, such as work zones, incidents, routing advisories, etc.

The proposed VDMS software system consisted of five different software programs. Two programs, namely UVA Server and VDMS Manager, were developed by UVA CTS. Three other programs, namely VTTI Server, RSE Application, and OBE/DAS Application, were developed by the Virginia Tech Transportation Institute (VTTI) Center for Technology Development (CTD). A conceptual diagram of the system is presented in Figure 1.

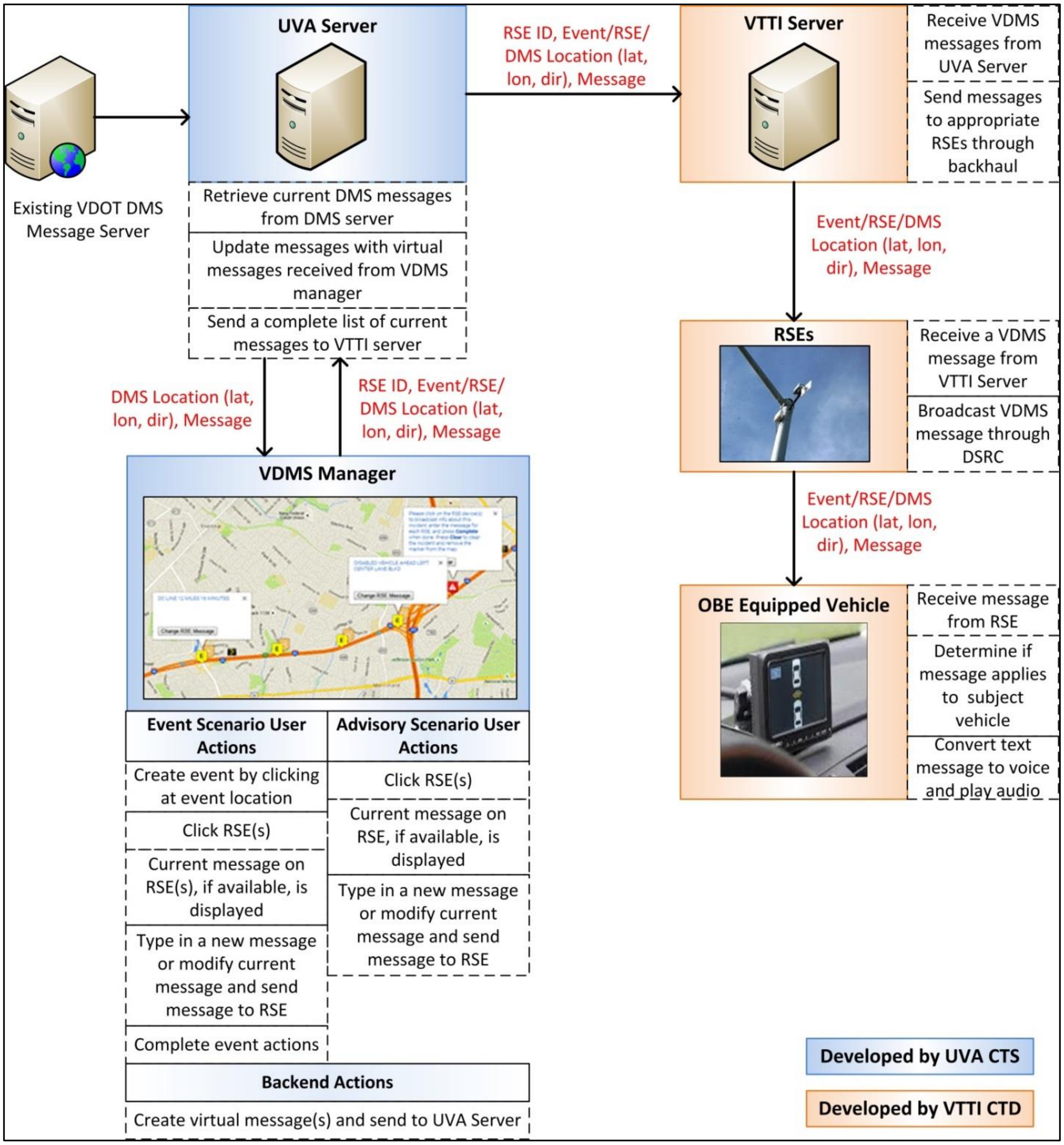


Figure 1. Conceptual diagram of the VDMS system.

A brief description of the operational concept presented in Figure 1 is provided below:

1. VDMS Manager is the main software interface of the VDMS system and is meant to be used by system operators, such as an operator at a traffic operations center (TOC).
    a. The VDMS application automatically retrieves current DMS messages from the remote DMS message server at a prespecified time interval.

    b. A user (an operator at a TOC, for example) then creates additional virtual DMSs and appropriate messages based on the scenario being dealt with.
    c. Once a full set of messages (actual and virtual) are ready, these messages are sent to the server at VTTI.
2. The server at VTTI receives the actual and virtual DMS messages from VDMS Manager, and sends appropriate messages—selected based on the communication boundary of each RSE—to each RSE through the backhaul network.
3. The RSE application then receives the messages from the VTTI server and broadcasts these messages through DSRC.
4. The OBE/DAS application receives the messages and selects appropriate messages for the subject vehicle based on the location and the heading of the vehicle.
5. Finally, the OBE/DAS application converts the selected text messages into audible messages and provides these to the driver.

System Development

Based on the conceptual diagram of the VDMS system, five actual applications were developed. This section first describes the study network used in this research, then provides details on how each individual application was developed and how messages were transmitted between these applications or servers.

Study Network

The study network was a 5-mile section (between mile marker [MM] 62 and MM 67) on I-66 on the Virginia Connected Vehicle Test Bed in Northern Virginia (Figure 2). The yellow icons represent the four RSEs that were used and the black icons represent two existing DMS signs in the eastbound (EB) direction. See Table 1 for more details on RSEs and DMSs. The RSEs were mapped to the closest General Advisory (GA) DMS sign downstream of that RSE. Since no suitable westbound DMS GA signs were found, no RSEs were mapped in the westbound (WB) direction.

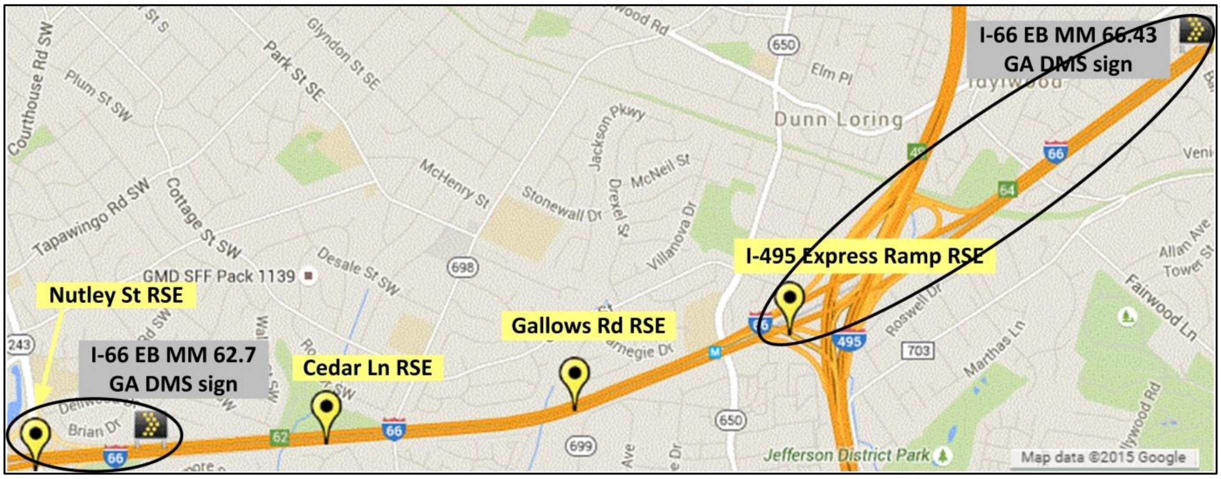


Figure 2. Study network.

Table 1. List of DMSs and RSEs

RSE	RSE Latitude	RSE Longitude	RSE Location	Mapped EB DMS	Mapped EB DMS Latitude	Mapped EB DMS Longitude
Cab13-I-495ExpressRamp	38.883888	-77.224468	I-495 Express IL Ramp to I-66 WB	CMS 0066 E 06643 GA	38.89611	-77.2014
Cab62GallowsRd	38.880525	-77.236652	I-66 EB 0.5 mi upstream of Gallows Rd underpass	None		
Cab581CedarLn	38.879084	-77.250714	I-66 EB 0.2 mi upstream of Cedar Ln underpass	None		
Cab533Nutley	38.877851	-77.267199	Nutley St SB On Ramp to I-66 EB	CMS 0066 E 06270 GA	38.87865	-77.2607

Application Development

In order to run the VDMS software, a computer with an Internet connection is required. A laptop or desktop of medium performance should be sufficient. The system has been tested on Windows 7 and Windows 8 with the latest versions of Microsoft Internet Explorer and Google Chrome browsers, and on a Mac with Safari and Google Chrome. The VDMS system does not work with Mozilla Firefox or older versions of Internet Explorer (6, 7, and 8) on the Windows platform. Javascript must be enabled in the browser.

Descriptions of each of the five software applications are provided below.

UVA Server

UVA Server is a Java program that runs every 10 seconds in an infinite loop on a server housed at the University of Virginia. On each run, it retrieves DMS messages currently posted on existing physical DMS signs from the VDOT DMS message server (VDOT Data Sharing, http://www.vdotdatasharing.org) and filters only the messages posted on two DMS signs (DMS signs on I-66 EB at MM 62.7 and MM 66.43) that were mapped to four RSEs on I-66 between MM 62.0 and MM 64.5 as shown in Figure 2. The VDOT-posted messages are made available to VDMS Manager for display in the user interface (UI). UVA Server also consults the list of virtual messages that VDMS Manager maintains. For each RSE and direction, it then combines the messages from the two sources to create the list of current messages, always pre-emptying the VDOT-posted DMS messages in favor of the operator-posted VDMS messages.

Specifically, if a message is posted by VDOT on a DMS and the operator also posted a virtual message on the corresponding RSE and direction, then UVA Server will select the operator's virtual message for that RSE and direction. If there is a message posted by VDOT on a DMS but no virtual message posted by the operator on the corresponding RSE and direction, UVA Server will use the VDOT-posted message for that RSE and direction. When there is no message posted on the DMS or when the RSE and direction are not mapped to any DMSs, UVA Server will select the VDMS message posted by the operator. If there is neither a DMS nor a VDMS message for a particular RSE and direction, UVA Server will select no messages for that RSE and direction.

When the list of current messages is created, it is compared against the list of previous messages to search for changes. A change is defined as any difference in the text of the message between the current version and the previous version for an RSE and direction. If a change is found, then a JavaScript Object Notation (JSON) message entry is created for the RSE and direction that exhibited the change. The list of all changes is packaged together as a single JSON message and is sent to VTTI Server for consumption. If no changes are found, then no communication is initiated with VTTI Server. In both cases, the list of current messages is saved for use during the next run of UVA Server, at which point it will become the list of previous messages.

VDMS Manager

VDMS Manager is the software interface to the VDMS system and is meant to be accessed and utilized by system users, such as the operators at a TOC. It runs in the user's Web browser, is written in Javascript, and makes use of the Google Maps Javascript application programming interface (API) version 3. The same computing server that runs UVA Server also runs an Apache Web server that hosts VDMS Manager and is accessed using the assigned VDMS Uniform Resource Locator (URL). To communicate back to this server, Hypertext Transfer Protocol (HTTP) POST requests are issued. Data from the HTTP POST requests are processed and saved on the server using PHP.

On initialization, VDMS Manager loads the RSE icons and places them on a map centered on I-66. Then, it loads the file containing the most recently posted DMS messages by VDOT (created by UVA Server) and populates the pop-up windows of the corresponding RSEs and directions. For context, VDMS Manager also loads the DMS signs and represents them with a chevron icon, .

In an advisory scenario (in which the user posts a message that is not associated with a particular location), the user clicks on the directional icon of the RSE, types in the message, and clicks the

“Change RSE Message” button in the pop-up window. VDMS Manager captures the virtual message text, sanitizes it (by keeping only alphanumerical characters and spaces), and sends an HTTP POST request to the server to update the current VDMS message file with the sanitized message text, the RSE ID, and the latitude and longitude of the RSE. Updating the entry results in creating a new entry if one is not already present or modifying the existing entry otherwise. The file with the current VDMS messages is read by UVA Server. VDMS Manager also displays the new message in the pop-up window for the RSE and direction until the user changes the message.

In an event scenario (in which the user posts a message associated with a particular location), the user clicks on the map at the event location to create the event. The user then clicks on the RSE(s) that will receive the post. When the “Send Message to RSE” button is pressed, an association between the newly created event and that RSE is created. The purpose of this association is to differentiate between the case when the RSE coordinates have to be sent in the message posted on the RSE (advisory scenario) and the case when the event coordinates have to be sent in the messages posted to the RSE (event scenario). After the user types in the messages and completes the entry process, VDMS Manager sends an HTTP POST request to the server to update the current VDMS message file with the sanitized message text, the RSE ID, and the latitude and longitude of the event location (which are derived directly from the map by VDMS Manager) for each RSE and direction associated with the incident. As in the case of the advisory scenario, the new message is displayed in the pop-up window of the directional RSE icon. When a message posted on an RSE and direction is changed by the user, VDMS Manager, besides showing the change in the pop-up window, also sends an HTTP POST request to the server to modify the entry in the current VDMS message file.

To delete (clear) a message, the user simply deletes the message text from the pop-up window. After this action, VDMS Manager will display an empty message if that RSE and direction are not mapped to a DMS or if no DMS messages are currently displayed by VDOT on the DMS mapped to that RSE and direction. Otherwise, VDMS Manager will display the current DMS message from the mapped DMS sign. When an event is cleared with its “Clear” button, all messages related to the event that had been posted on RSEs are deleted, the association between the event and any RSEs is broken, and the event marker is removed from the map. The changes made by the operator on the rest of the map are preserved.

Given that the primary goal of this research project was to demonstrate and evaluate the feasibility of a prototype VDMS system, it was determined to utilize only one VDMS message per RSE at any time (irrespective of direction), for the sake of simplicity. For example, if there is a message for the EB direction, sending a message for the WB direction to the same RSE will overwrite the message for the EB direction. This prototype system can be later enhanced to handle multiple messages for a production level system.

VTTI Server

VTTI Server receives a list of messages packaged in JSON format from UVA Server via an HTTP POST request, and sends out messages to the appropriate RSEs through the backhaul network. VTTI Server confirms receipt of the JSON message using a Traveler Information Message (TIM) RSE status code that is checked by UVA Server.

The outbound message to RSE Application includes a vendor code in the TIM message so that OBE/DAS Application is able to identify the data as a virtual dynamic message.

RSE Application

RSE Application receives a message from VTTI Server and broadcasts this message through DSRC at 1-second intervals. Note that a 25–40 second delay between the moment when messages are sent to an RSE and when they are posted to an RSE is possible. This communication delay is mainly caused by the VDMS system being operated using the existing testbed configuration (i.e. update intervals for various equipment). When a production-level VDMS system is developed, the update intervals will need to be adjusted to reduce this delay.

OBE/DAS Application

OBE/DAS Application receives a message and determines if the received message is valid for the subject vehicle, based on the location and heading of the vehicle and the location of the event (or RSE or DMS) being considered. If a message is found to be valid, OBE/DAS Application converts the message text into an audio message (speech) and "speaks" it to the driver. Otherwise, the message is discarded.

The standard OBE/DAS program, developed by VTTI CTD, was modified in order to be able to receive a VDMS message transmission, and a mechanism to convert messages from text to voice was established.

Message Communications between Servers and Applications

Within the VDMS system, there are three critical data communication channels between UVA Server and the VDOT Data Sharing Server, VDMS Manager, and VTTI Server. This section provides details on how this communication of messages was established.

UVA Server – VDOT Data Sharing Server

The connection between UVA Server and the VDOT Data Sharing Server consists of bidirectional Internet communication. During each run, UVA Server accesses the DMS Sign Status webpage on the Virginia Traffic and Video Data (TVD) Sharing Site. UVA Server makes an HTTP request for the set of current messages posted on the DMS signs and receives an Extensible Markup Language (XML) response that is parsed internally. The messages posted on the two DMS signs mapped to RSEs are extracted from the XML. If one or both mapped DMSs display a NULL message, are listed as inactive, are missing from the XML response, or if the request fails for any reason, the software assumes that there is currently no message posted on that DMS(s) and will display no message in the pop-up window of the corresponding RSE and direction. Figure 3 shows an example of the XML response sent by the VDOT TVD server with the XML element describing the Nutley Street DMS sign.


```
- <item>
    <title>Sign NOVACMS2480821 is on</title>
  - <link>
      <![CDATA[http://www.vdotdatasharing.org/xmldb/DmsSignStatus/NovaSTC-NOVACMS2480821]]>
    </link>
  - <guid>
      <![CDATA[http://www.vdotdatasharing.org/xmldb/DmsSignStatus/NovaSTC-NOVACMS2480821]]>
    </guid>
  - <description>
      <![CDATA[[pt25o0][jp3][jl3][fo1]DISABLED VEHICLE[fo][nl1][jl3][fo1]MM 64[fo][nl1][jl3][fo1]RIGHT LANE BLKD[fo] ]]>
    </description>
    <georss:point>38.878658 -77.260735</georss:point>
  </item>
```


Figure 3. Extract of XML response from VDOT Data Sharing Server.

UVA Server uses the title, description, and georss:point fields. The DMS sign name is replaced by its mapped RSE ID and direction. The latitude and longitude coordinates are extracted from georss:point, and the message text is extracted from the description field by dropping the line breaking and formatting character sequences and any other non-alphanumeric characters. This processing is shown in Table 2.

Table 2. XML Fields from Response Used by UVA Server

XML Field	Description	XML Value	Processed Value
title	DMS sign name and display status	Sign NOVACMS69112 is on	RSE Id: Cab533Nutley Direction: E
description	Text of the message currently displayed on the DMS sign	[pt25o0][jp3][jl3][fo1]DISABLED VEHICLE[fo][nl1][jl3][fo1]MM 64[fo][nl1][jl3][fo1]RIGHT LANE BLKD[fo]	Message Text: DISABLED VEHICLE MM 64 RIGHT LANE BLKD
georss:point	Global Positioning System (GPS) location of the DMS sign	38.878658 -77.260735	Lat: 38.878658 Lon: -77.260735

UVA Server – VDMS Manager

The connection between UVA Server and VDMS Manager is two-way local communication happening on the UVA computing server. UVA Server prepares a JSON file with the most recent messages retrieved from the VDOT Data Sharing website for use by VDMS Manager to populate the pop-up windows of the RSEs and directions mapped to physical DMS signs. The file contains the following attributes: RSE ID, direction, location latitude and longitude (where location is DMS location), and message text. An example showing the attributes and their values is presented below:

```
[
  {
    "RSEId": "Cab533Nutley",
    "locLat": " 38.877851 ",
    "locLon": "- 77.267199 ",
    "dir": "E",
    "msgTxt": "DC LINE 12 MILES 17 MINUTES"
  },
  {
    "RSEId": "Cab13-I-495ExpressRamp",
    "locLat": " 38.883888",
    "locLon": "-77.224468 ",
    "dir": "E",
    "msgTxt": ""
  }
]
```

Figure 4. Example of JSON File Prepared by UVA Server for VDMS Manager.

VDMS Manager maintains a file containing the current operator-posted VDMS messages. This file is read by UVA Server to derive the most recently posted message for each RSE and direction and to send message changes to VTTI Server. The file contains the following attributes: RSE ID, direction, location latitude and longitude (where location can be RSE or event location), message source (always "VDMS," signifying operator-posted virtual message) and message text. Sample data from this file are shown in the example below:

```
Cab13-I-495ExpressRamp,38.00002,-77.00002,W,VDMS,test message on Cab13-I-495ExpressRamp RSE for WB
Cab533Nutley,38.87865,-77.260735,E,VDMS,test message on Cab533Nutley for EB
Cab581CedarLn,38.879084,-77.250714,W,VDMS,test message on Cab581CedarLn for WB
```

Figure 5. Example of VDMS Manager File of Most Recent Operator-Posted VDMS Messages.

UVA Server – VTTI Server

The connection between UVA Server and VTTI Server is one-way Internet communication from UVA Server to VTTI Server. By combining the operator-posted VDMS messages with the VDOT-posted DMS messages, UVA Server creates a list of current messages to be transmitted to the RSE(s), as exemplified in Table 3 rows (a) and (b). Row (c) from same table shows the changes between the previous and current messages, and row (d) shows the same list packaged as a JSON-formatted message ready to be sent to VTTI Server. The JSON message is sent in an HTTP POST request. VTTI Server processes the request and sets a status code locally on the computing server at Virginia Tech that is read by UVA Server. The attributes for each element of the JSON array are RSE ID, location latitude and longitude (where location can be DMS, RSE, or event location), direction, and message text.

Table 3. Compiling Message Changes by UVA Server

(a) Sample list of previous messages	Cab13-I-495ExpressRamp,38.883888,-77.224468,E,VDMS, Cab62GallowsRd,38.880525,-77.236652,E,VDMS, Cab581CedarLn,38.879084,-77.250714,E,VDMS, Cab533Nutley,38.877851,-77.267199,E,VDOT,DC LINE 12 MILES 17 MINUTES
(b) Sample list of current messages	Cab13-I-495ExpressRamp,38.883888,-77.224468,E,VDMS, Cab62GallowsRd,38.880525,-77.236652,E,VDMS, Cab581CedarLn,38.879778,-77.242106,E,VDMS, ACCIDENT AHEAD RIGHT LANE BLOCKED Cab533Nutley,38.879778,-77.242106,E,VDOT,ACCIDENT AHEAD RIGHT LANES BLOCKED DC LINE 12 MILES 22 MINUTES
(c) Changes between previous and current message lists	Cab581CedarLn,38.879778,-77.242106,E,VDMS, ACCIDENT AHEAD RIGHT LANE BLOCKED Cab533Nutley,38.879778,-77.242106,E,VDOT,ACCIDENT AHEAD RIGHT LANES BLOCKED DC LINE 12 MILES 22 MINUTES

(d) JSON message sent by UVA Server to VTTI Server corresponding to changes from (c)	{
	"messages": [
	{
	"RSEId": "Cab533Nutley",
	"locLat": "38.879778",
	"locLon": ,-77.242106",
	"dir": "E",
	"msgTxt": "ACCIDENT AHEAD RIGHT LANES BLOCKED DC LINE 12 MILES 22 MINUTES"
	},
	{
	"RSEId": "Cab581CedarLn",
	"locLat": "38.879778",
	"locLon": "-77.242106",
	"dir": "E",
	"msgTxt": "ACCIDENT AHEAD RIGHT LANE BLOCKED"
	}
	]
	}

Operational Scenarios

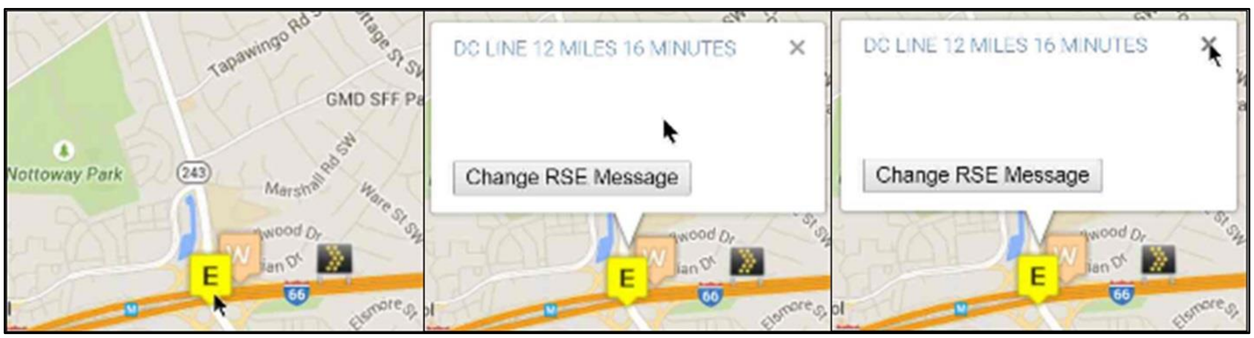
The main users of the VDMS system will be TOC operators, who will use the VDMS UI to enter new messages, modify existing messages already posted by VDOT on physical DMS signs, create incidents and other VDMS events, and clear incidents. The beneficiaries of these messages will be motorists traveling through the CV environment in vehicles equipped with devices capable of communicating with the CV infrastructure.

The CV-environment devices that are used by the VDMS system are RSE and OBE units that communicate using DSRC. To be able to integrate the messages posted by VDOT on traditional DMSs, the RSEs were mapped to DMS signs (see Figure 2 and Table 1). The VDMS software system associates the messages posted on those DMS signs with the mapped RSEs on the fly. For ease of distinguishing between directions when posting messages on RSE, the directional icons E for EB and W for WB were used to represent each RSE in the VDMS UI. The operator clicks on the icon that corresponds to the desired direction to post a message.

A typical VDMS operator session unfolds as follows: The operator logs in to the VDMS website and is presented with a map showing the area where the RSEs are located (I-66 in Northern Virginia between Nutley St. and I-495). At initialization, the system retrieves DMS messages posted on two existing DMS signs and associates them with the corresponding RSEs. The map can be manipulated using standard controls: pan, zoom in, and zoom out. The user (operator) has a choice of running three scenarios: an informational scenario, an event scenario, or an advisory scenario. These scenarios can be run one after the other during the course of a session, and the process within each scenario can be repeated as many times as needed.

Informational Scenario

In an informational scenario, the user checks the messages posted on the RSEs and makes no changes to the system. The user clicks the RSE and the message that is currently posted will appear in a pop-up window. This message could be the message currently posted on the physical DMS associated with the RSE retrieved from the VDOT DMS server or could have been created or modified by the operator during a previous operator action. These steps are graphically illustrated below in Figure 6.



(1) User clicks on an RSE.

(2) A message currently posted on an RSE is shown in the pop-up window.

(3) User closes the pop-up window.

Figure 6. Sample informational scenario.

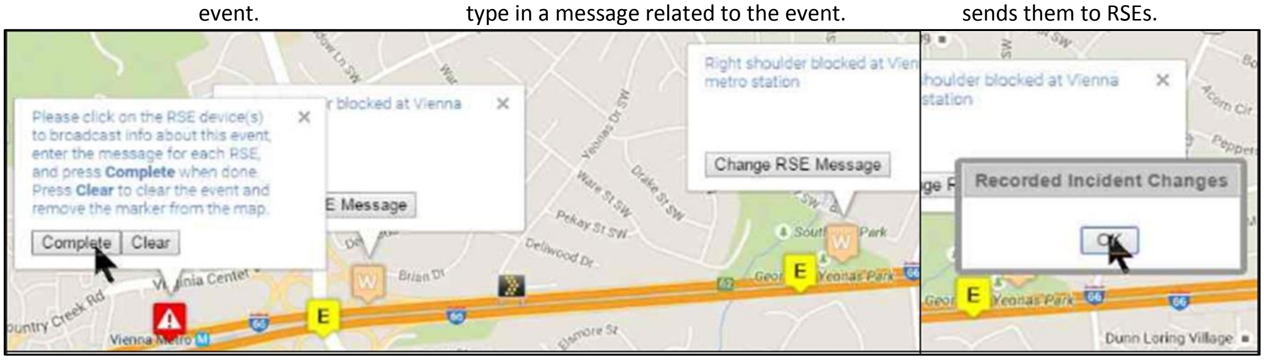
Event Scenario

In an event scenario, the operator creates an event and then associates one or more RSEs with that event. To create an event, the operator clicks on the map at the event location and an event marker ( ) with a pop-up window containing instructions on managing the event appears. The operator can click on any RSE using the directional icons (and) and post messages on the RSE related to that event. The steps for posting messages and event clearing are very simple and almost self-explanatory, but for thoroughness they are detailed below. Multiple events at the same time are allowed. Screen shots illustrating the sequences for one incident posted to multiple RSEs and multiple incidents are shown in Figure 7 and Figure 8, respectively.

When the directional RSE (or) icon is clicked, a pop-up window appears that contains the current message posted on that RSE for that direction, if any. To change the current message, the operator clicks the "Change RSE Message" button, which causes the pop-up window to become editable and the button to change its label to "Send Message to RSE." After typing in the message, the operator clicks the "Send Message to RSE" button to associate the RSE with the opened event and prepare the message to be sent to the RSE. When messages for all RSEs related to this event have been entered, the operator goes back to the event pop-up window to click the "Complete" button. This effectively sends the operator message(s) to the RSE(s). Failing to click "Complete" will result in the operator's changes not being posted to the RSE. During the course of an event, the operator can change the RSE messages as needed. To delete the event (for example clear an incident, close a work zone, etc.) and clear all messages associated with it, the operator clicks the "Clear" button in the event pop-up window.

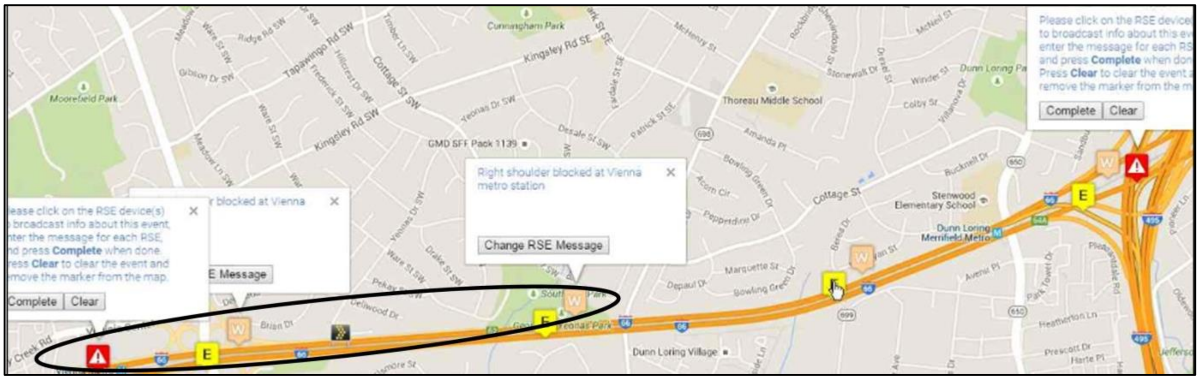
As stated earlier, only one VDMS message per RSE is allowed at any time. Therefore, an RSE and direction can be associated with only one event. If the operator desires to change the association of an RSE to a different incident, the first incident has to be closed first to break the current association. Then, the second incident has to be created, and the RSE needs to be clicked to create a new association.

(1) User clicks on the map to create an event. (2) User clicks on an RSE and prepares to type in a message related to the event. (3) User changes messages and sends them to RSEs.



(4) User types in messages about the event on multiple RSEs and completes the event by instructing the system to post messages to RSEs. (5) Confirmation of the message post is displayed.

Figure 7. Sample event scenario for one incident with messages on multiple RSEs.



(1) User creates a new incident event.

(2) Messages for both incidents are now posted to RSEs.

(3) The first incident and its messages have been cleared from the associated RSEs.

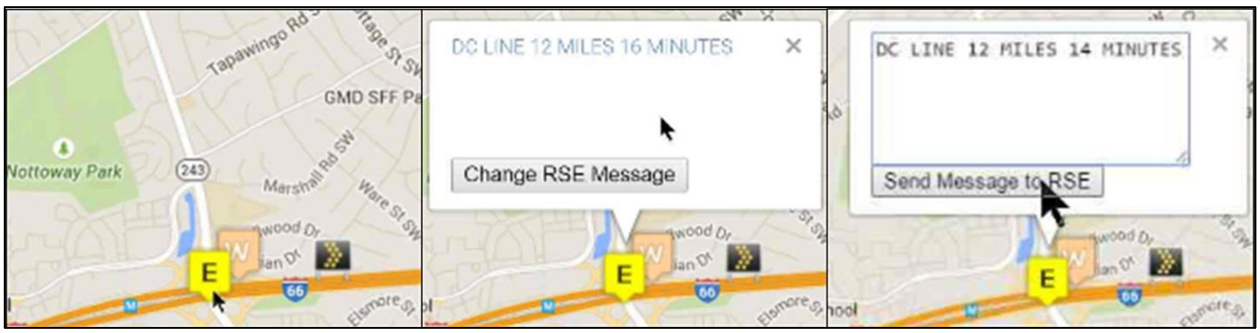
(4) The second incident and its messages have been cleared from the associated RSEs.

Figure 8. Sample event scenario for two concurrent incidents.

Advisory Scenario

An advisory scenario can be run only when there are no open events. This type of scenario is useful for posting advisory messages of a general nature that are not associated with a specific geographic location. Running an advisory scenario consists of changing an existing message or creating a new one (if the current message on the RSE is empty) and the process is very simple and self-explanatory. For thoroughness, the steps are detailed below and shown in Figure 9 and Figure 10.

The user clicks the “Change RSE Message” button for an RSE, types in the desired message, and clicks the “Send Message to RSE” button. To clear the message for an RSE, the user has to send an empty message to the RSE by clicking the RSE icon, then the “Change RSE message” button, effectively deleting the message, and finally clicking the same button, which now is labeled “Send Message to RSE.”

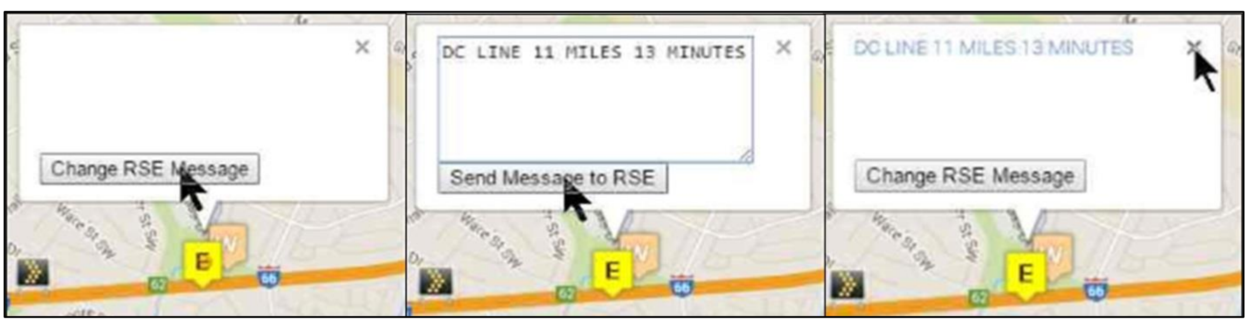


(1) User clicks on an RSE.

(2) A message currently posted on an RSE is shown in the pop-up window.

(3) User changes the message and sends it to an RSE.

Figure 9. Sample advisory scenario for changing an existing message.



(1) User wants to post a new message on an RSE.

(2) User types in a new message and prepares to send it to an RSE.

(3) A message is posted to an RSE.

Figure 10. Sample advisory scenario for creating a new message.

System Testing and Demonstration

After all the individual applications and programs for the VDMS system were developed, UVA Server and VDMS Manager were installed on a desktop computer at UVA. Three other applications were installed on the corresponding equipment, the VTTI server, RSEs, and OBEs.

Note that the VDMS manager UI can be accessed from any Web browser on any computer or mobile device.

Two-step integration testing and a demonstration were carried out to confirm that the whole VDMS system performed as intended. A summary of activities in each integration test and the demonstration is provided below:

1. First integration test at the Smart Road Connected Vehicle Test Bed in Blacksburg, Virginia on June 22, 2015
    a. An initial integration test was conducted at the Smart Road Connected Vehicle Test Bed to make sure the intended functions of the VDMS system were well executed in a closed highway environment.
    b. One UVA researcher was stationed in the Smart Road control room to post messages and two UVA researchers were in the car, one to drive and the other to check the message delivery.
    c. Several test cases (i.e., all EB RSE messages, all WB RSE messages, mixed directional messages, etc.) were successfully completed.
2. Second integration test on I-66 in Northern Virginia on July 21, 2015
    a. The next step of integration testing was done on the actual roadway, a 5-mile section of the I-66 Northern Virginia Connected Vehicle Test Bed.
    b. One UVA researcher was stationed at a remote location near the test site to post messages and three UVA researchers were in the car along I-66, one to drive and the others to confirm that the messages were properly delivered and to record any relevant information.
    c. Similar to the first integration test, several test cases (base case for current DMS messages, all EB RSE messages, all WB RSE messages, mixed directional messages, etc.) were all successfully conducted without any issues.
3. Demonstration to VDOT on I-66 in Northern Virginia on July 29, 2015
    a. After the proper functioning of the VDMS was confirmed, a demonstration was provided to two VDOT officials (Ms. Candice Gibson and Mr. James Sullivan) working at the McConnell Public Safety and Traffic Operations Center (PSTOC).
    b. One UVA researcher was stationed at the PSTOC to post appropriate messages depending on the test case being demonstrated. Two UVA researchers and two VDOT officials were in the car together, driving along the I-66 test corridor to experience and evaluate the actual audio and text messages being delivered through an in-vehicle device.
    c. The test cases demonstrated were identical to the ones used in the second integration test (base case for current DMS messages, all EB RSE messages, all WB RSE messages, mixed directional messages, etc.). The demonstration was successful without any issues.

In conclusion, it was confirmed through two integration tests and a demonstration that the VDMS system can successfully execute its intended functions, providing audio readings of existing, modified, and newly created messages to drivers. Detailed plans for each integration test and the demonstration are presented in Appendix A – VDMS Testing Plan and Demonstration.

VDMS Evaluation

In order to evaluate the VDMS system as a tool to support the TOC's efforts to manage traffic, operational testing was conducted with the actual operators at the McConnell PSTOC. More specifically, the goal of the operational testing was to gain feedback from TOC operators on the usability and the effectiveness of the VDMS system as an information dissemination tool to support advanced traffic management.

The operational testing was performed in August 2015, with testing times determined on-site based on the availability of operators and notified by the PSTOC. A total of 15 operators participated. Two UVA CTS researchers and a TOC operator were stationed at the PSTOC, with the VDMS Manager Web interface on a laptop computer.

Operational Testing Procedure

An operator went through the following procedure during the operational testing. First, a brief tutorial on general CV concepts, VDMS system overview, and the VDMS Manager manual were provided to the operator. The TOC operator then used VDMS Manager to create virtual DMSs and messages to manage traffic for 11 incidents (1 example, 5 actual, and 5 hypothetical incidents). Finally, feedback from the operators on the usability, and the effectiveness of the VDMS system was gathered. The whole operational testing for each operator took approximately 1.5 hours. Detailed descriptions of each step of the operational testing are presented below.

VDMS Tutorial (10 min) – Appendix B – Background Information for Operators

The purpose of the tutorial was to provide necessary information to operators so that they could become familiar with the VDMS system and general CV concepts. The tutorial included the following contents, and a background information document (see Appendix B – Background Information for Operators) was distributed to operators in advance:

- CV concepts
- VDMS system overview
- VDMS Manager program manual – short version
- VDMS Manager tutorial with a video clip

Entrance Survey (5 min) – Appendix C – Entrance Survey

The first step of the operational testing was to assess the level of the operator's overall understanding on the traditional DMS system and the VDMS system. An entrance survey questionnaire with seven questions was prepared and attached (Appendix C – Entrance Survey).

Operational Testing Followed by Post-Incident Survey (60 min) – Appendix D – Incident Information Sheet and Appendix E – Post-Incident Survey

The next step was for the operator to actually use VDMS Manager to create virtual DMSs and messages to manage incidents.

For this, a total of 11 incidents were prepared for operators to input into the VDMS system. For each incident, an incident information sheet with details (time, location, incident type, lane block, etc.) was prepared (see Appendix D – Incident Information Sheet):

- The first incident was an example incident that was used for practice in the beginning.
- The next five incidents were actual incidents that took place in May and June 2015 and were carefully selected from the Regional Integrated Transportation Information System (RITIS) database. These selected incidents were of various types (disabled vehicle, accident, congestion, expect delay, Intelligent Transportation Systems (ITS) installation, parade, etc.) and ranged between MMs 60 and 67 on the eastbound lane of I-66.
- The remaining five incidents were hypothetical, prepared to cover more complete incident cases.

For each of the 11 incidents, the following steps were performed:

- UVA CTS researchers first gave an incident information sheet (Appendix D – Incident Information Sheet) to the operator.
- The operator then used VDMS Manager to post messages that he or she felt were relevant to manage the incident given. These messages were saved automatically for a follow-up analysis.
- Once the operator finished posting messages, a post-incident survey (Appendix E – Post-Incident Survey) was completed by the operator to gather feedback on the operator's actual experience with each incident.

Exit Survey (10 min) – Appendix F – Exit Survey

Finally, at the end of operational testing, the operator completed an exit survey, which mainly asked for an overall impression and assessment of the VDMS system as an alternative information dissemination tool.

Results

Results obtained from the entrance survey, post-incident survey, and exit survey, respectively, are presented in this section, followed by an overall summary of significant findings.

Entrance Survey Results

The purpose of the entrance survey was twofold: (1) to establish a baseline of operators' opinions on the performance of the current DMS system, and (2) to identify any concerns that the proposed VDMS system may be able to address. Overall, it was found that operators were mostly content with the current state of DMS software and were okay working within the limitations of the system. However, many acknowledged that definite improvements could be made.

The most cited issues that operators had with the current DMS system had to do with location of signs, limited space on signs to display information, and the ability to keep signs up to date. The prototype VDMS system in its current state can certainly address the first two issues operators cited with DMS systems. VDMS allows for messages to be dispersed without the physical limitation of a sign, which means that a message can always be provided in a location that is helpful to drivers making decisions about the information posted. The audible component of the system should also allow for additional information without restrictions on how much visual information a driver can process without a distraction. On the other hand, operators who cited the challenge of keeping the signs up to date were discussing limitations of the current system and the fact that the information at TOCs is not always up-to-date. This issue will need to be investigated further and may be addressed with a more enhanced VDMS system in the future.

In addition, based on responses to the entrance survey, operators seemed to feel that the most important aspects of creating a message were clarity and accuracy. These challenges will persist and perhaps even become more important as the VDMS allows for more flexible information provision. Operators will need to use their own judgment regarding where to post messages so that they are useful to drivers, which necessitates quality training for operators before the VDMS system is actually implemented.

Post-Incident Survey Results

The post-incident survey was used to observe how operators would use the VDMS system differently than the existing DMS software. A variety of both real and hypothetical incident scenarios (see Appendix E – Post-Incident Survey) were provided to operators, who were asked to post actual messages using the VDMS system. Operators were then asked their opinions on the differences between the DMS and VDMS systems.

In general, comments on the post-incident survey stated that several limitations of the DMS system can be addressed by using the VDMS system.

- Operators liked the flexibility provided by the VDMS system in terms of message contents and locations. Some of the operators actually took advantage of the fact that they could provide more detailed information at more locations in the VDMS system. When more information was provided, it often included more detail on the incident (such as type of road work underway or special event information). Some operators even posted an estimated time for the incident to be cleared.
- Operators also appreciated the additional capabilities, such as being able to post messages to multiple locations at once.
- It was also stated that it takes operators less time to post messages, which may be an artifact of being able to post messages to multiple locations at once.

On the other hand, it was acknowledged that the flexibility and the capability of the VDMS software in providing more detailed and customized messages could potentially lead to more complex decision-making for operators. Some of the findings observed were:

- Operators were inconsistent in their message locations and the number of messages they placed across incidents; for a given incident, operators did not always place the same messages in the same spots.
- Operators were not consistent with the terminology they used. For example, some used mile markers to list locations while others used an exit.

As such, new guidelines and training would need to be developed and provided in the event of implementation of the VDMS system.

Finally, some specific improvements to the VDMS software were also brought up, generally regarding some specific functions that DMS software provides that VDMS in its current state does not. Specifically, timers for work zones and special events are available in the evaluated TOC's DMS system but not in the current prototype version of the VDMS software. This is a minor concern that can be easily addressed by the production-level VDMS system.

Exit Survey Results

The exit survey was intended to give operators a chance to state their final opinions on the VDMS system relative to their current software after they had a chance to simulate actual incidents. Based on the responses, operators felt that the VDMS software could address concerns with both the physical limitations of the current DMS system and some of the limitations of the current DMS software. According to the responses, VDMS improves the ease of selecting incident location, selecting where to post the message, and creating more detailed/customized messages, all while providing an improved operator experience interacting with the VDMS software.

Figure 11 and Table 4 show the responses to Question 3 of the exit survey, which asked the survey respondents to circle which of the two systems was more efficient for each of the following performance metrics:

a) Number of Units of Information
b) Customizable Messages
c) Relevant Information to Motorists
d) Flexibility of Selecting Geographic Location
e) Ease of Operator Use
f) Time to Post Message

Figure 11. Operator responses to Question 3 of exit survey.

Table 4. Operators' preference between DMS and VDMS

Survey Questions	DMS		VDMS		Both	
Units of Information	4	29%	9	64%	1	7%
Customizeable Messages	2	14%	11	79%	1	7%
Relevant Information to Drivers	4	29%	8	57%	2	14%
Flexibility in Location Selection	3	21%	8	57%	3	21%
Ease of Use for Operators	2	15%	10	77%	1	8%
Time to Post Messages	2	14%	11	79%	1	7%
Total	**17**	**20%**	**57**	**69%**	**9**	**11%**

Clearly, the absolute majority of respondents felt that, for most of the stated performance metrics, VDMS was the more efficient system to use. Stated benefits and concerns of the system were consistent with those recorded in the post-incident survey. Benefits were centered on customization and flexibility, while concerns tended to target providing consistent messages to motorists.

Overall, VDMS was preferred by about 70% of responses while DMS was favored by 20%. About 10% of responses liked both DMS and VDMS. Notably, the operators appreciated three specific enhancements of the VDMS system: customizable messages, ease of use, and time to post messages, all of which had nearly 70% preference. With this result, it would be reasonable to conclude that the TOC operators see the VDMS system as a tool to support the improved TOC operations.

Conclusions

DMSs have been widely used to deliver traveler information and have proven to be effective for DOTs. However, key limitations exist: (1) existing DMSs are limited in managing dynamic situations since they are only available at relatively sparsely spaced fixed locations, (2) visually reading DMS messages is distracting to drivers, and (3) installation and maintenance of DMSs is expensive. To address these limitations, a smartphone-based VDMS application was developed under a separate project, in the first round of CVI-UTC projects. This application uses smartphones to provide an audible "reading" of the current DMS messages to drivers when they enter a geographic zone in the proximity of the fixed sign. In addition, the project used extensive testing with a driving simulator to prove that VDMSs are less distracting and more informative than traditional physical DMSs.

In this project, building upon the previous work, the UVA CTS team developed a more advanced, second generation of the VDMS system that is fully integrated in the DSRC environment of the Virginia Connected Vehicle Test Bed. The proposed VDMS software system consists of five different software programs. Two programs (UVA Server and VDMS Manager) were developed by UVA CTS while three other programs (VTTI Server, RSE Application, and OBE/DAS Application) were developed by VTTI CTD. The highlights of the enhanced VDMS system developed in this research project are:

- This VDMS system used four of 40+ DSRC-based RSEs installed at the Virginia Connected Vehicle Test Bed, for communications.
- VDMS Manager has the capability to virtually "build" new DMSs and to create modified or new messages for those DMSs.
- The messages to be presented are flexible enough to cover a variety of information, such as work zone safety/management, incident response and management, and routing advisories.

To gather actual feedback from intended users on the usability and the effectiveness of the VDMS system as an information dissemination tool to support advanced traffic management, an operational test was carried out with TOC operators at the McConnell PSOTC. Over the course of three surveys (entrance, post-incident, and exit), it was observed that operators' opinions were mostly positive and that the VDMS provided an improved message-posting process for operators and more-detailed information at more-appropriate locations for motorists. The VDMS system received higher ratings from most operators than the existing physical DMS. Finally, given that the VDMS system developed in this study is one of many mobility applications that will be made feasible under a CV environment, efforts should be made to develop and evaluate other CV mobility applications to appropriately gauge the potential of the CV environment.

Limitations, and Future Work

The VDMS system developed, demonstrated, and evaluated in this research project is a prototype system that utilizes only four out of more than 40 RSEs installed in the Virginia Connected Vehicle Test Bed. Given the proven feasibility and effectiveness of the VDMS system as a supporting tool to enhance TOC operations, this prototype system is ready to advance to a production-level comprehensive VDMS system. In order to achieve this, the following critical and additional features is recommended:

- Inclusion of all 40+ RSEs in the Virginia Connected Vehicle test bed;
- Capability to handle multiple messages at the same time per each RSE;
- Timers for messages for planned events (i.e. work zones and special events);
- An enhanced user interface; and
- Near real-time message transmission.

TOC operators should also be administered additional training sessions which include defining the impact range of an event, identifying relevant information for messages, proving an appropriate level of detail, and wording/grammar of messages. These additional training sessions will ensure the VDMS system functions as intended and the maximum enhancement is achieved.

Appendix/Appendices

Appendix A – VDMS Testing Plan and Demonstration

VDMS Testing Plan – First Integration Test – Smart Road in Blacksburg on June 22, 2015

- **In the control room at VTTI (Operator)**
  - Post message “test Eastbound incident. Shoulder blocked ahead.” on all EB RSEs.
  - Mark time when message posted to RSE (reason: to measure delay)
- **In the car (Driver and passenger)**
  - Listen to messages while going Eastbound (away from VTTI) – OBE software should speak the messages inside the car and messages should be heard
  - Listen to messages while going Westbound (toward VTTI) – no messages should be heard
  - If allowed by VTTI protocol: Passenger: mark time when message heard first (for ex.: on phone timer app). The reason is to measure the delay from when message is posted to when it is first heard. If possible, passenger marks on a phone mapping app where the messages was first heard.

Test 2: Post messages on all Westbound RSEs

- **In the control room at VTTI (Operator)**
  - Post message “test Westbound incident. Right lane blocked ahead.” on all WB RSEs.
  - Mark time when message posted to RSE (reason: to measure delay)
- **In the car (Driver and passenger)**
  - Listen to messages while going Westbound (toward VTTI) – OBE software should speak the messages inside the car and messages should be heard
  - Listen to messages while going Eastbound (away from VTTI) – no messages should be heard
  - If allowed by VTTI protocol: Passenger: mark time when message heard first (for ex.: on phone timer app). The reason is to measure the delay from when message is posted to when it is first heard

Test 3: Post messages on some Eastbound RSEs

- **In the control room at VTTI (Operator)**
  - Post message “test Eastbound incident at sites 4, 5, and 6. Congestion ahead.” on Site 4, Site 5, and Site 6 Eastbound RSEs.
- **In the car (Driver and passenger)**
  - Listen to messages while going Eastbound (away from VTTI) – OBE software should speak the messages inside the car and messages should be heard in the communication radii of Sites 4, 5, and 6. No messages should be heard in the communication radii of Sites 1, 2, and 3.
  - Listen to messages while going Westbound (toward VTTI) – no messages should be heard

Test 4: Post messages on some Eastbound RSEs and some Westbound RSEs

- **In the control room at VTTI (Operator)**
  - Post message “test Eastbound message at site 1. DC line 12 miles 14 minutes” on Site 1 EB RSE.
  - Post message “test Westbound message at sites 2, 3, and 4. Right two lanes blocked ahead.” on Sites 2, 3, and 4 Westbound RSEs.

    - Post messages “test Eastbound message at sites 5 and 6.” on Sites 5 and 5 Eastbound RSEs.
- **In the car (Driver and passenger)**
    - Listen to messages while going Eastbound (away from VTTI) – OBE software should speak the messages inside the car and respective Eastbound messages should be heard in the communication radii of Sites 1, 5, and 6. No messages should be heard in the communication radii of Sites 2, 3, and 4.
    - Listen to messages while going Westbound (toward VTTI) – OBE software should speak the messages inside the car and the Westbound messages should be heard in the communication radii of Sites 2, 3, and 4. No messages should be heard in the communication radii of Sites 1, 5, and 6.

At the end of the field test

- Passenger and operator exchange information. Passenger informs the operator about what was heard, when, and where.
- Depending on the results of the tests, some tests may be repeated and some more tests may be introduced.

Time Plan

- 8:00 All meet at B122E.
  David gets the server started. (VDMS server doc)
  David checks the addresses for VDMS Manager and Status Site.
- 8:30 All leave to Northern Virginia.
- 10:30 All arrive at Starbucks (3011 Nutley St SW, Fairfax, VA 22031).
  Drop off Brittany (and pick up Rob).
- 11:00 All start testing – see "Test Cases" for details.
- 13:30 All drive back to Charlottesville.
- 15:30 David shuts off the server and recap.
- 16:00 Adjourn

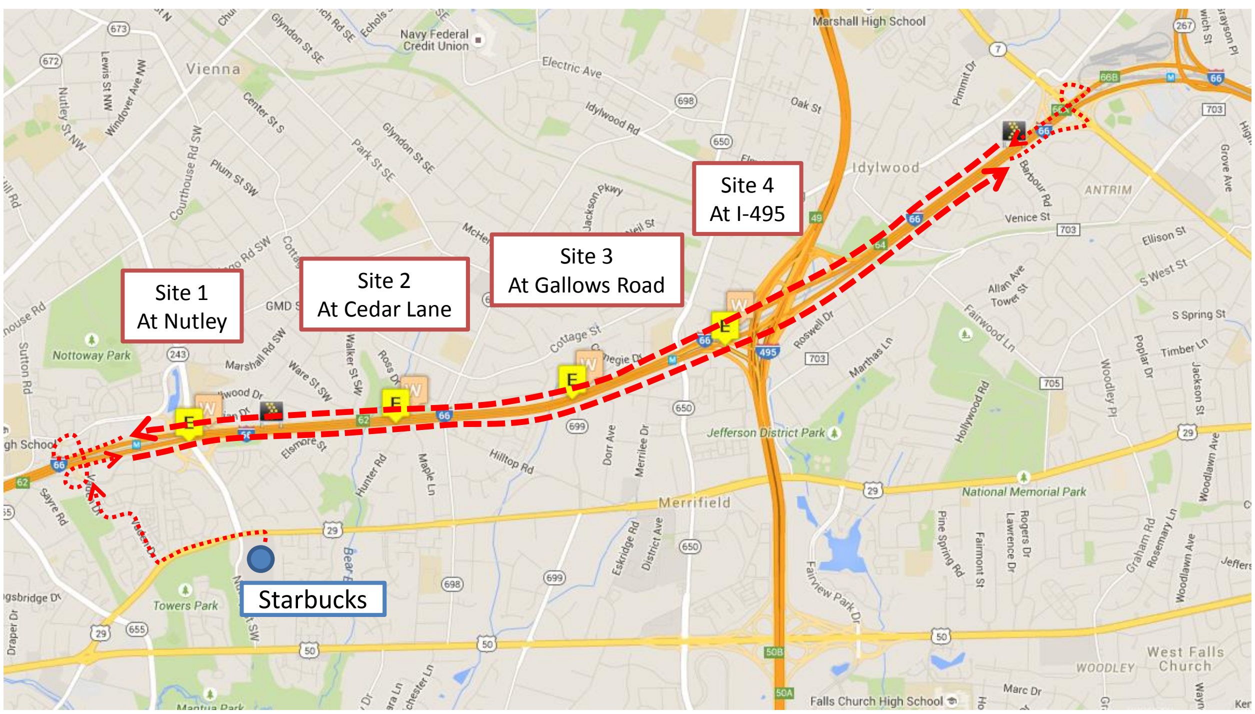
Participants and Duties

In the vehicle

- David Recht – drive, support field testing
- Hyungjun Park – lead field testing, communicate with Brittany
- Alona Green – record the times of message delivery

At a remote location (Starbucks for field testing)

- Brittany Hungate – post messages using the VDMS manager for each test case



Test 1: Base Case for Current Messages on DMSs

Brittany Hungate at a remote location (or in the control room at PSTOC)

1. Open the VDMS manager site at http://128.143.35.88/VDMS_withWB/VDMS.html.
2. Initialize messages for all four RSEs.
   a. Click a location (near the DMS on the right) to create an imaginary incident.
   b. Post a message "initialization" to all four eastbound RSEs.

c. Click “complete” and verify at http://128.173.194.102:5052/api/uva/status that
    i. For all RSEs, “msgTxt” is “initialization” and “Status” is “0.”
d. Finally, click “clear” and verify that
    i. For RSE #1, “msgTxt” is the current message and “Status” is “0.”
    ii. For RSE #2-4, “msgTxt” is still “initialization” and “Status” is “5.”

3. Then, inform Hyungjun Park that all the messages have been initialized.

Hyungjun Park in the car

4. Drive to Eastbound and listen to messages – one current message from RSE #1 should be heard.
    a. Alona records the times when messages are heard.
5. Drive back to Westbound and listen to messages – no message should be heard.
6. Inform Brittany that Test 1 is completed.

Test 2: Messages on all Eastbound RSEs

Brittany Hungate at a remote location (or in the control room at PSTOC)

1. Click a location (near the DMS <u>on the right</u>) to create an imaginary incident.
2. Post messages on all Eastbound RSEs (from left to right).
    a. “Testing Eastbound Approaching Site 1 at Nutley”
    b. “Testing Eastbound Approaching Site 2 at Cedar Lane”
    c. “Testing Eastbound Approaching Site 3 at Gallows Road”
    d. “Testing Eastbound Approaching Site 4 at I-495”
3. Click “complete” and mark the time when message posted to RSEs (reason: to measure delay).
4. Verify, for all RSEs, “msgTxt” is what you just typed in and “Status” is “0.”
5. Then, inform Hyungjun Park that all messages have been posted.

Hyungjun Park in the car

6. Drive to Eastbound and listen to messages – four messages should be heard inside the car.
    a. Alona records the times when messages are heard.
7. Drive back to Westbound and listen to messages – no message should be heard.
8. Inform Brittany that Test 2 is completed.

Brittany Hungate at a remote location (or in the control room at PSTOC)

9. Click “clear” and verify that
    a. For RSE #1, “msgTxt” is the current message and “Status” is “0.”
    b. For RSE #2-4, “msgTxt” is still what was posted and “Status” is “5.”

Test 3: Messages on all Westbound RSEs

Brittany Hungate at a remote location (or in the control room at PSTOC)

1. Click a location (near the DMS <u>on the left</u>) to create an imaginary incident.
2. Post messages on all Westbound RSEs (from left to right).
    a. “Testing Westbound Approaching Site 1 at Nutley”
    b. “Testing Westbound Approaching Site 2 at Cedar Lane”
    c. “Testing Westbound Approaching Site 3 at Gallows Road”
    d. “Testing Westbound Approaching Site 4 at I-495”
3. Click “complete” and mark the time when message posted to RSEs (reason: to measure delay).
4. Verify, for all RSEs, “msgTxt” is what you just typed in and “Status” is “0.”
5. Then, inform Hyungjun Park that all messages have been posted.

Hyungjun Park in the car

6. Drive to Eastbound and listen to messages – no message should be heard.
7. Drive back to Westbound and listen to messages – four messages should be heard inside the car.
    a. Alona records the times when messages are heard.
8. Inform Brittany that Test 3 is completed.

Brittany Hungate at a remote location (or in the control room at PSTOC)

9. Click “clear” and verify that
    a. For RSE #1, “msgTxt” is the current message and “Status” is “0.”

    b. For RSE #2-4, “msgTxt” is still what was posted and “Status” is “5.”

Test 4: Message on two Eastbound RSEs (#1 and #3) and two Westbound RSEs (#2 and #4)

Brittany Hungate at a remote location (or in the control room at PSTOC)

1. Click a location (near the DMS <u>on the right</u>) to create an imaginary incident.
2. Post messages on two Eastbound RSEs (#1 and #3).
    a. “Testing Eastbound Approaching Site 1 at Nutley”
    b. “Testing Eastbound Approaching Site 3 at Gallows Road”
3. Click “complete” and mark the time when message posted to RSEs (reason: to measure delay).
4. Click a location (near the DMS <u>on the left</u>) to create an imaginary incident.
5. Post messages on two Westbound RSEs (#2 and #4).
    a. “Testing Westbound Approaching Site 2 at Cedar Lane”
    b. “Testing Westbound Approaching Site 4 at I-495”
6. Click “complete” and mark the time when message posted to RSEs (reason: to measure delay).
7. Verify, for all RSEs, “msgTxt” is what you just typed in and “Status” is “0.”
8. Then, inform Hyungjun Park that all messages have been posted.

Hyungjun Park in the car

9. Drive to Eastbound and listen to messages – two messages from RSE #1 and #3 should be heard.
    a. Alona records the times when messages are heard.
10. Drive to Westbound and listen to messages – two messages from RSE #2 and #4 should be heard.
    a. Alona records the times when messages are heard.
11. Inform Brittany that Test 4 is completed.

Brittany Hungate at a remote location (or in the control room at PSTOC)

12. Click “clear” for both incidents and verify that
    a. For RSE #1, “msgTxt” is the current message and “Status” is “0.”
    b. For RSE #2-4, “msgTxt” is still what was posted and “Status” is “5.”

Demonstration Date: Wednesday, July 29, 2015 10:00AM-12:00PM

- 10:00 – 10:15 VDMS System Updates at PSTOC
  - Initial VDMS manager screen – four RSEs and two DMSs
  - Only one message per RSE
  - Messages with and without incident
  - Multiple incidents
- 10:15 – 11:15 Field Demonstration on I-66
  - Four test cases, each takes about 15 minutes
- 11:15 – 12:00 Discussion on TOC Operational Testing at PSTOC – if time permits
- 12:00 Adjourn

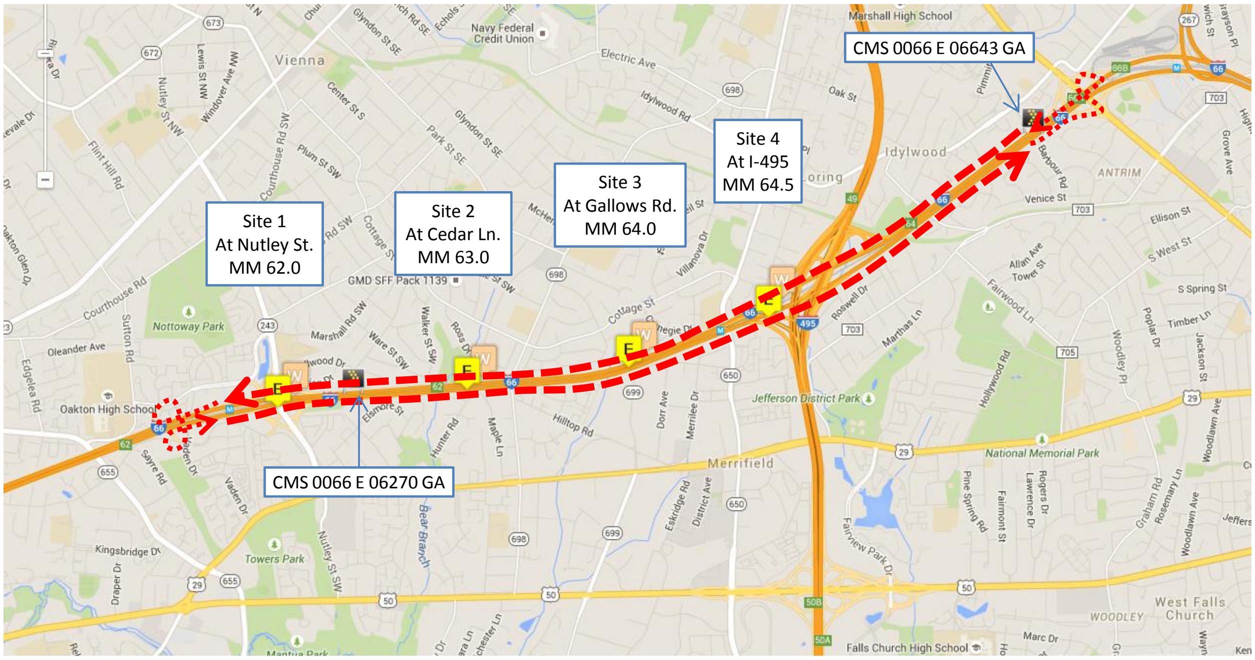
Participants and Duties

In the vehicle

- David Recht – drive, support demonstration
- Hyungjun Park – lead demonstration, communicate with Brittany
- Candice Gibson and James Sullivan

At a remote location (PSTOC for demonstration)

- Brittany Hungate – post messages using the VDMS manager for each test case



Test 1: Base Case for Current Messages on DMSs

Brittany Hungate at PSTOC

1. Open the VDMS manager site at http://128.143.35.88/VDMS_withWB/VDMS.html.
2. Initialize messages for all four RSEs.
   a. Click a location (near the DMS on the right) to create an imaginary incident.
   b. Post a message "initialization" to all four eastbound RSEs.
   c. Click "complete" and verify at http://128.173.194.102:5052/api/uva/status that
      i. For all RSEs, "msgTxt" is "initialization" and "Status" is "0."
   d. Finally, click "clear" and verify that

i. For RSE #1, “msgTxt” is the current message and “Status” is “0.”
ii. For RSE #2-4, “msgTxt” is still “initialization” and “Status” is “5.”

3. Then, inform Hyungjun Park that all the messages have been initialized.

Hyungjun Park in the car

4. Drive to Eastbound and listen to messages – one current message from RSE#1 should be heard.
5. Drive back to Westbound and listen to messages – no message should be heard.
6. Inform Brittany that Test 1 is completed.

Test 2: Messages on all Eastbound RSEs

Brittany Hungate at PSTOC

1. Click a location (near the DMS on the right) to create an imaginary incident.
2. Post messages on all Eastbound RSEs (from left to right).
    a. “Testing Eastbound Approaching Site 1 at Nutley”
    b. “Testing Eastbound Approaching Site 2 at Cedar Lane”
    c. “Testing Eastbound Approaching Site 3 at Gallows Road”
    d. “Testing Eastbound Approaching Site 4 at I-495”
3. Click “complete.”
4. Verify, for all RSEs, “msgTxt” is what you just typed in and “Status” is “0.”
5. Then, inform Hyungjun Park that all messages have been posted.

Hyungjun Park in the car

6. Drive to Eastbound and listen to messages – four messages should be heard inside the car.
7. Drive back to Westbound and listen to messages – no message should be heard.
8. Inform Brittany that Test 2 is completed.

Brittany Hungate at PSTOC

9. Click “clear” and verify that
    a. For RSE #1, “msgTxt” is the current message and “Status” is “0.”
    b. For RSE #2-4, “msgTxt” is still what was posted and “Status” is “5.”

Test 3: Messages on all Westbound RSEs

Brittany Hungate at PSTOC

1. Click a location (near the DMS on the left) to create an imaginary incident.
2. Post messages on all Westbound RSEs (from left to right).
    a. “Testing Westbound Approaching Site 1 at Nutley”
    b. “Testing Westbound Approaching Site 2 at Cedar Lane”
    c. “Testing Westbound Approaching Site 3 at Gallows Road”
    d. “Testing Westbound Approaching Site 4 at I-495”
3. Click “complete.”
4. Verify, for all RSEs, “msgTxt” is what you just typed in and “Status” is “0.”
5. Then, inform Hyungjun Park that all messages have been posted.

Hyungjun Park in the car

6. Drive to Eastbound and listen to messages – no message should be heard.
7. Drive back to Westbound and listen to messages – four messages should be heard inside the car.
8. Inform Brittany that Test 3 is completed.

Brittany Hungate at PSTOC

9. Click “clear” and verify that
    a. For RSE #1, “msgTxt” is the current message and “Status” is “0.”
    b. For RSE #2-4, “msgTxt” is still what was posted and “Status” is “5.”

Test 4: Message on two Eastbound RSEs (#1 and #3) and two Westbound RSEs (#2 and #4)

Brittany Hungate at PSTOC

1. Click a location (near the DMS on the right) to create an imaginary incident.
2. Post messages on two Eastbound RSEs (#1 and #3).

    a. "Testing Eastbound Approaching Site 1 at Nutley"
    b. "Testing Eastbound Approaching Site 3 at Gallows Road"
3. Click "complete."
4. Click a location (near the DMS <u>on the left</u>) to create an imaginary incident.
5. Post messages on two Westbound RSEs (#2 and #4)
    a. "Testing Westbound Approaching Site 2 at Cedar Lane"
    b. "Testing Westbound Approaching Site 4 at I-495"
6. Click "complete."
7. Verify, for all RSEs, "msgTxt" is what you just typed in and "Status" is "0."
8. Then, inform Hyungjun Park that all messages have been posted.

Hyungjun Park in the car

9. Drive to Eastbound and listen to messages – two messages from RSE #1 and #3 should be heard.
10. Drive to Westbound and listen to messages – two messages from RSE #2 and #4 should be heard.
11. Inform Brittany that Test 4 is completed.

Brittany Hungate at PSTOC

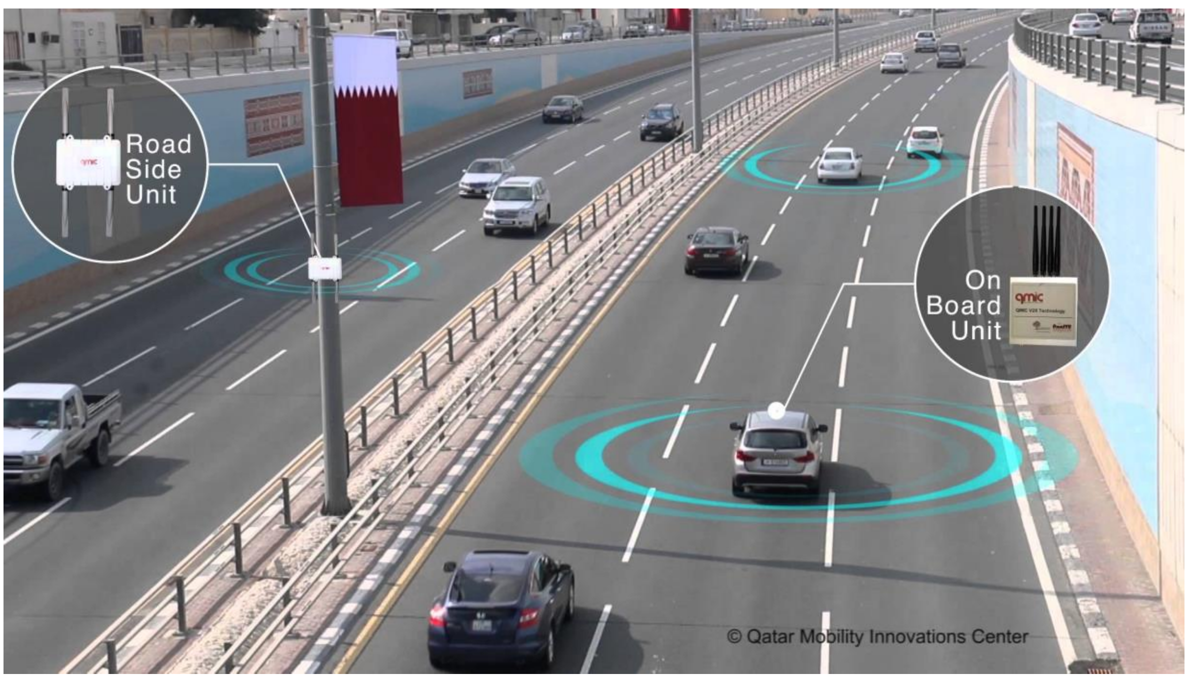
12. Click "clear" for both incidents and verify that
    a. For RSE #1, "msgTxt" is the current message and "Status" is "0."
    b. For RSE #2-4, "msgTxt" is still what was posted and "Status" is "5."

Appendix B – Background Information for Operators

Connected Vehicle Concept

As wireless communications technologies have matured and the challenges of providing safer, more efficient, and predictable surface transportation services increase, new paradigms for vehicle surveillance and control systems have been being proposed. One with great potential is the Connected Vehicle environment.

Connected Vehicle is defined as "a suite of technologies and applications that use wireless communications to provide connectivity that can deliver transformational safety, mobility, and environmental improvements in surface transportation." Under the Connected Vehicle environment, with the provision of a wireless communications network, vehicles equipped with an on-board equipment (OBE) can communicate with other vehicles on the roadways and surrounding infrastructure instrumented with a road side equipment (RSE) as well. With this wireless connectivity, more detailed vehicular data can be collected at a more frequent interval (up to 10 times per second) while the infrastructure will have the capability of delivering more sophisticated information to targeted motorists. A simple concept is presented below.



Connected Vehicle Concept (http://i.ytimg.com/vi/XlGc4nxYuGM/maxresdefault.jpg)

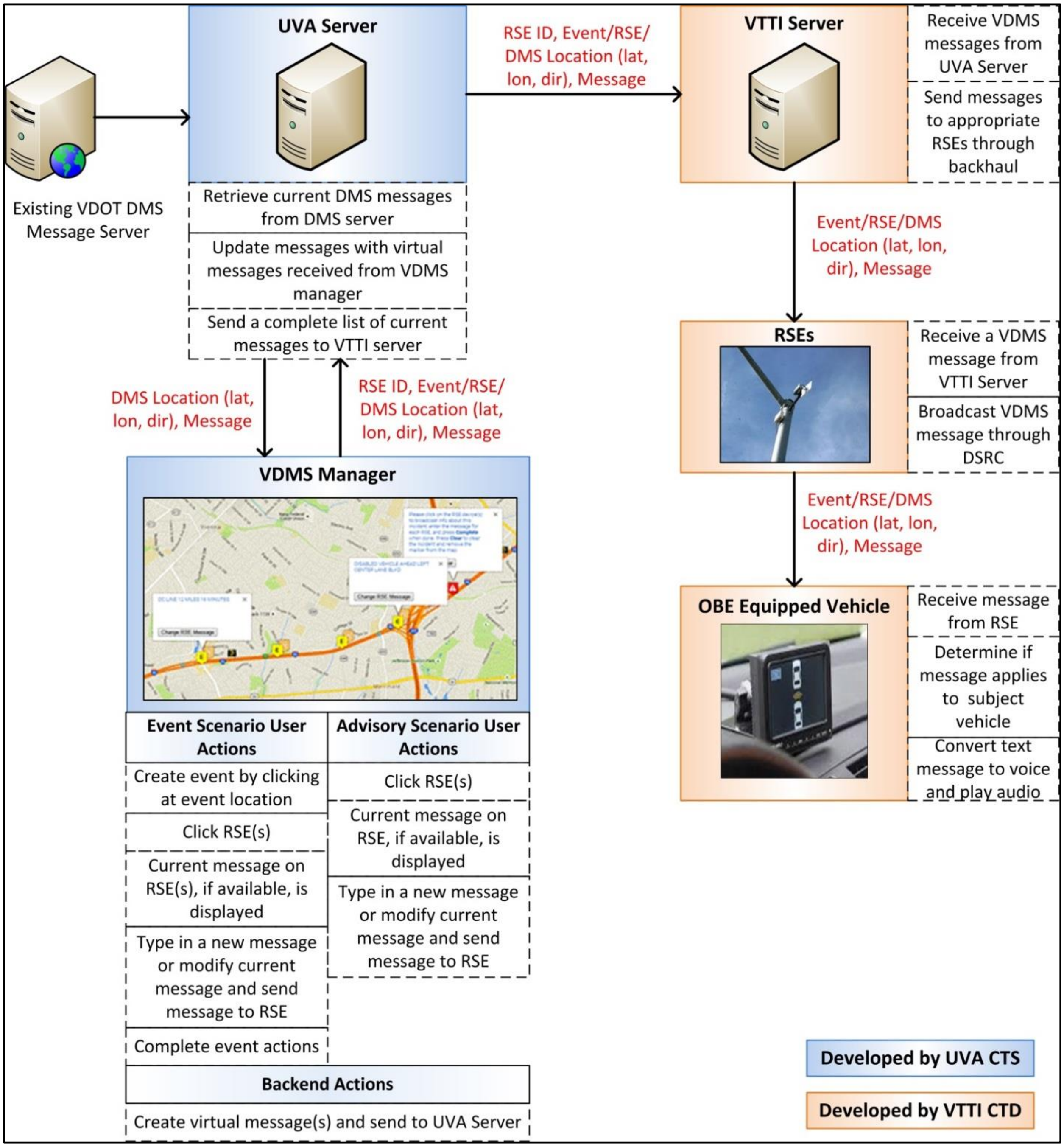
The potential of Connected Vehicle applications is considered to be so significant that it can be represented as a "revolution" in how transportation services are provided and to significantly improve transportation safety, mobility, and productivity. The VDMS system is one of the good example applications.

Virtual Dynamic Message Sign System Overview

The VDMS system is similar to traditional DMSs in that they both inform drivers and passengers of upcoming situations and warnings, but is accomplished through different ways. The VMDS system is built on a connected vehicle environment and thus traveler information messages are sent from a server at a remote location (UVA and VTTI), to Road Side Equipment (RSE), and then to On-Board Equipment (OBE) wirelessly. The VDMS system not only provides audio readings of the current text messages on DMSs but also allows the user (i.e. operators at a traffic operation center) to create additional virtual DMSs and type in new messages for these virtual DMSs.

The proposed VDMS software system consists of five different software programs. Two programs, namely UVA Server and VDMS Manager, were developed by UVA CTS (University of Virginia Center for Transportation Studies). Three other programs, namely VTTI Server, RSE (Road Side Equipment) Application, and the OBE/DAS (On-Board Equipment/Data Acquisition System) Application, were developed by VTTI CTD (Virginia Tech Transportation Institute Center for Technology Development). A conceptual diagram is presented in the Figure on the next page and a step-by-step description is provided below:

- The UVA server automatically retrieves current DMS messages from the remote DMS message server at a pre-specified time interval. Then a message table for RSEs is created by matching DMSs with corresponding RSEs. Finally, a completed message table is sent to the Virginia VTTI server.
    - Note here that if a modified or new message for any RSE is received from the VDMS manager program (see below), current messages in the message table are replaced by the new/modified messages.
- The VDMS manager program is the main software interface to the VDMS system and is meant to be used by system operators, such as an operator at a traffic operations center (TOC).
    - A user (or an operator at a TOC, for example) first specifies the location of the event in concern.
    - A user then selects RSEs and modifies the current message or creates a new message for the selected RSEs.
    - Finally this new or modified message will be sent to the UVA server.
- The VTTI server receives a table of messages with corresponding RSE IDs from the UVA server, and sends messages out to appropriate RSEs through the backhaul network.
- The RSE application receives a message from the VTTI server and broadcasts this message through DSRC.
- The OBE application receives a message and determines if the received message is valid for the subject vehicle, based on the location and heading of the vehicle, and the location of the event (or a DMS) being considered. If a message is found to be valid, the OBE application converts the selected text messages into audible messages and provides these to the driver.

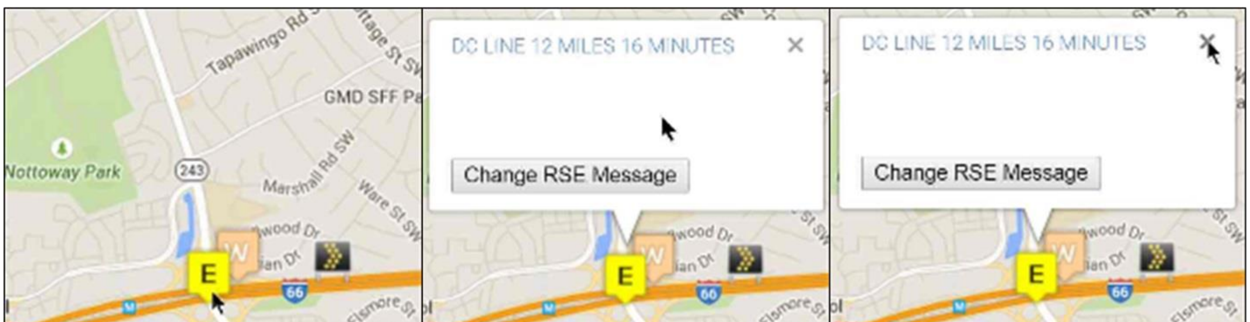


Conceptual Diagram of the Virtual Dynamic Message Sign System

The CV environment devices that are used by the VDMS system are RSE (Road Side Equipment) and OBE (On-Board Equipment) units that communicate using DSRC. To be able to integrate the messages posted by VDOT on the traditional DMS assets, the RSEs were mapped to DMS signs. The VDMS software system associates the messages posted on those DMS signs with the mapped RSEs on the fly. For ease of distinguishing between directions when posting messages on RSE, directional icons E for Eastbound and W for Westbound are used to represent each RSE. The operator clicks on the icon that corresponds to the direction where she or he wants to post the message.

A typical VDMS operator session will unfold as follows: The operator logs into the VDMS website and is presented with a map showing the area where the RSEs are located (I-66 in Northern Virginia between Nutley St and I-495). At initialization, the system retrieves DMS messages posted on DMS signs and associates them with the corresponding RSE. The map can be manipulated using existing controls: pan, zoom in and out.

At first, the user just checks the messages posted on the RSEs and makes no changes to the system. The user clicks the RSE and the message that is currently posted will appear in a pop-up window. This message could be the message currently posted on the physical DMS associated with the RSE retrieved from the VDOT DMS server or could have been created or modified by the operator during a previous operator action. These steps are graphically illustrated the Figure below.



(a) User Clicks on RSE	(b) Message Currently Posted on RSE Shown in Pop-Up Window	(c) User Closes Pop-Up Window

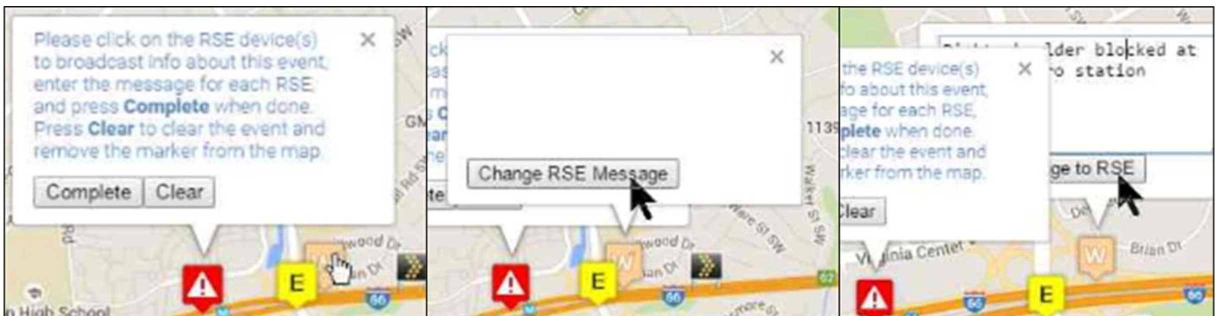
Sample Informational Scenario

In an event scenario, the operator creates an event and then associates one or more RSEs with that event. To create an event, the operator clicks on the map at the event location and an event marker with a pop-up window containing instructions on managing the event appears. The operator can click on any RSE using the directional icons and post messages on the RSE related to that event. The steps for posting messages and event clearing are very simple and almost self-explanatory, but for completion they are detailed below. Multiple events at the same time are allowed. A few important screen shots are shown in the Figure below.

When the directional RSE icon is clicked, a pop-up window appears that contains the current message posted on that RSE for that direction, if any. To change the current message, the operator presses the "Change RSE Message" button, which causes the pop-up window to become editable and the button to change its label to "Send Message to RSE". After typing in the message, the operator presses the "Send

Message to RSE" button to associate the RSE with the opened event and prepare the message to be sent to the RSE. When messages for all RSEs related to this event have been entered, the operator goes back to the event pop-up to press the "Complete" button. This effectively sends the operator message(s) to the RSE(s). Omitting to press "Complete" will result in the operator changes not being posted to the RSE. During the course of an event, the operator can change the RSE messages as needed. To delete the event (for example clear an incident, close a work zone, etc.) and clear all messages associated with it, the operator presses the "Clear" button from the event pop-up window.

At any point in time an RSE and direction can be associated with only one event. If the operator desires to change the association of an RSE to a different incident, the first incident has to be closed first to break the current association, then the second incident has to be created, and then the RSE clicked to create a new association.



(a) User Clicks on the Map to Create an Event

(b) User Clicks on an RSE and Prepares to Type In a Message Related to Event

(c) User Changed Message and Sends It to RSE

(d) User Typed In Messages about the Event on Multiple RSEs and Completes the Event by Instructing the System to Post Messages to RSEs

(e) Confirmation that Messages Have Been Posted to RSEs

Sample Scenario for One Incident Showing Message Posting on Multiple RSEs

Appendix C – Entrance Survey

Name: ___________________________________

1. On a scale of 1 - 5, with 1 being no familiarity and 5 being very familiar, **how familiar are you with Dynamic Message Signs (DMS)**?

   1 2 3 4 5

2. On a scale of 1 - 5, with 1 being no familiarity and 5 being very familiar, **how familiar are you with Virtual Dynamic Message Signs (VDMS)**?

   1 2 3 4 5

3. On a scale of 1-5, with 1 being inefficient and 5 being very efficient, **please describe the efficiency of existing DMS software in:**

Providing relevant <u>units of information</u> to drivers:	1	2	3	4	5
Customizing messages:	1	2	3	4	5
Providing information to relevant <u>geographic areas</u>:	1	2	3	4	5
Ease of operator use:	1	2	3	4	5

   Comments:

4. **Which of the following would improve the existing DMS software program?** Please **rank the options below**, with 1 being the most important and 4 being the least important.

   Additional Units of Information

   Customizable Messages

   Additional Geographic Locations

   Ease of Operator Use

5. **What are common obstacles to providing information to motorists using the DMS system?** Please list any in the space below.

6. **What is the most important factor in creating a message for the DMS system?** Please explain below.

7. **Are there any other improvements or adjustments that you would make to the existing DMS software program?** Please provide any comments below**.**

Appendix D – Incident Information Sheet

A total of 11 incidents were prepared for operators' input to the VDMS system in the operational testing:

- The first incident is an example incident that will be used for practice in the beginning.
- The next ten incidents are actual ones that took place in May and June 2015.
- The remaining five incidents are hypothetical, prepared to cover more complete incident cases.

A summary of these 11 incidents are presented in the table below (for record-keeping, five of the actual events have been deleted, but the numbers have not been adjusted in the numbering system shown below).

Category	NO	Event ID	Incident Type	Mile Marker	Start	Duration
Example	E0	NNO8366813-05032015	Vehicle Accident	66.1	5/3/2015 4:23	1:00
Actual	A1	INNO8366735-05032015	Vehicle Accident	62.0	5/3/2015 2:57	1:00
	A3	INNO8453757-05102015	Vehicle Accident	67.3	5/10/2015 6:35	1:52
	A8	INNO9018438-06242015	Disabled Vehicle	64.0	6/24/2015 17:44	1:01
	A9	SENO2900734-05242015-1	Parade	62.0	5/24/2015 9:00	0:24
	A10	WZNO2915981-06292015-1	ITS Equip Installation	65.1-66.4	7/9/2015 21:00	8:00
Hypothetical	H1	N/A	Vehicle Accident	61.5	5/2/2015 12:31	1:13
	H2	N/A	Spilled Cargo	62.2	5/6/2015 16:11	1:19
	H3	N/A	Car Fire	63.2	5/15/2015 00:11	1:50
	H4	N/A	Pavement Failure	64.2	5/29/2015 20:35	2:55
	H5	N/A	Overturned Vehicle	65.2	6/6/2015 11:11	3:20

E0. Example Incident (INNO08366813-05032015) for Practice ONLY

Incident Location

Initial Input

Start Time: May 3, 2015; 4:23 AM
Incident - Vehicle Accident;
I-66E; At mile marker 66.10;
1 vehicle; 0 injuries; 0 fatalities
East lane #2 closed 4:23 AM
East lane #3 closed 4:23 AM
East shoulder #4 closed 4:23 AM

Update 1

Time: May 3, 2015; 5:24 AM
East lane #2 open 5:24 AM
East lane #3 open 5:24 AM
East shoulder #4 open 5:24 AM

Final Input

End Time: May 3, 2015; 5:24 AM
All Travel Lanes Clear: May 3, 2015; 5:24 AM; 1 hour
Scene Clear: May 3, 2015; 5:24 AM; 1 hour
Event duration: 1 hour

Actual DMS Messages Posted (provided for the example incident only)

Start	*End*	*Messages*
5/3/2015 4:25:34 AM	*5/3/2015 5:24:34 AM*	*ACCIDENT EXIT 65 2 RIGHT LNS BLKD*

A1. Actual Incident 1 (INNO8366735-05032015)

Incident Location

Initial Input

Start Time: May 3, 2015; 2:57 AM
Incident - Vehicle Accident;
I-66E; At mile marker 62.00;
1 vehicle; 0 injuries; 0 fatalities
East shoulder #4 closed 2:57 AM

Final Input

Time: May 3, 2015; 3:58 AM
East shoulder #4 open 3:58 AM; 1 hour 1 minute
Event duration: 1 hour

A3. Actual Incident 3 (INNO8453757-05102015)

Incident Location

Initial Input

Start Time: May 10, 2015; 6:35 AM
Incident - Vehicle Accident;
I-66E; At mile marker 67.30;
2 vehicles; 0 injuries; 0 fatalities
East lane #3 closed 6:35 AM
East shoulder #4 closed 6:35 AM

Update 1

Time: May 10, 2015; 6:52 AM
East lane #2 closed 6:52 AM
East lane #3 closed 6:52 AM
East shoulder #4 closed 6:52 AM

Final Update

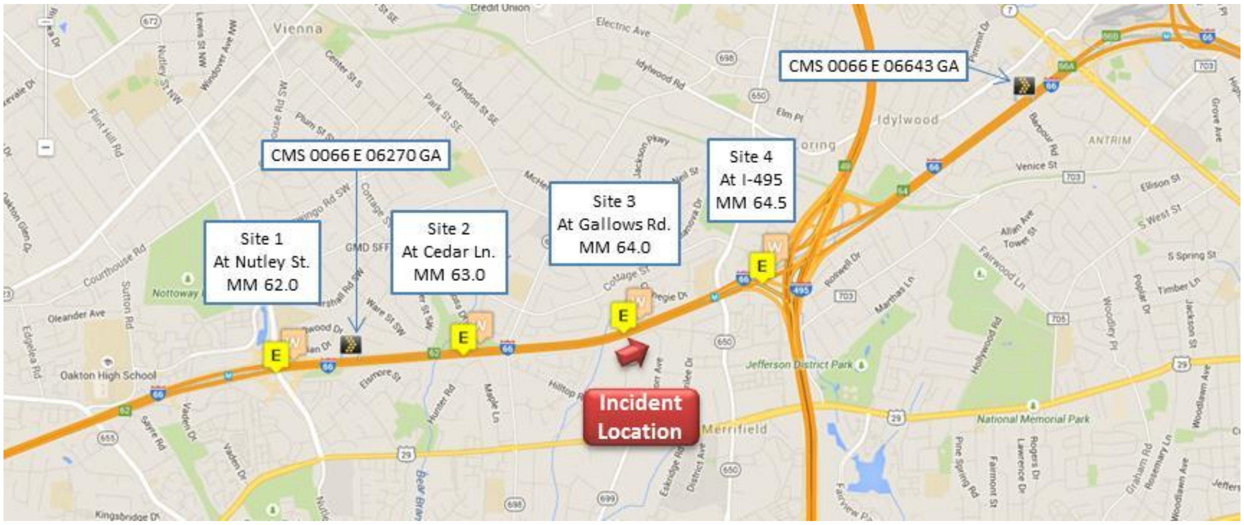
Time: May 10, 2015; 7:57 AM
East Lane #1 closed 7:57 AM
East lane #2 closed 7:57 AM
East lane #3 closed 7:57 AM
East shoulder #4 closed 7:57 AM

Final Input

End Time: May 10, 2015; 8:28 AM
All Travel Lanes Clear: May 10, 2015; 8:28 AM; 1 hour 53 minutes
Scene Clear: May 3, 2015; 8:28 AM; 1 hour 53 minutes
Event duration: 1 hour 53 minutes

A8. Actual Incident 8 (INNO9018438-06242015)

Incident Location



Initial Input

Start Time: June 24, 2015; 5:44 PM
Incident – Disabled Vehicle;
I-66E; At mile marker 64.0;
1 vehicle; 0 injuries; 0 fatalities
East lane #3 closed 5:44 PM
East shoulder #4 closed 5:44 PM

Final Input

End Time: June 24, 2015; 6:45 PM
All Travel Lanes Clear: June 24, 2015; 6:45 PM; 1 hour 1 minute
Scene Clear: May 3, 2015; 6:45 PM; 1 hour 1 minute
Event duration: 1 hour 1 minute

A9. Actual Incident 9 (SENO2900734-05242015-1)

Incident Location

Initial Input

Start Time: May 24, 2015; 9:42 AM
Incident - Parade;
I-66E; At mile marker 62;
0 vehicle; 0 injuries; 0 fatalities
East lane #1 closed 9:42 AM
East lane #2 closed 9:42 AM
East shoulder #3 closed 9:42 AM

Final Input

End Time: May 24, 2015; 10:06 AM
All Travel Lanes Clear: May 24, 2015; 10:06 AM; 24 minutes
Scene Clear: May 24, 2015; 10:06 AM; 24 minutes
Event duration: 24 minutes

A10. Actual Incident 10 (WZNO2915981-06292015-1)

Incident Location

Initial Input

Start Time: July 9, 2015; 9:00 PM
Incident – ITS Equipment Installation;
I-66E; At mile marker 65.10 to 66.4;
0 vehicle; 0 injuries; 0 fatalities
East Shoulder #0 closed 9:00 PM
East lane #2 closed 9:00 PM
East lane #3 closed 9:00 PM
East shoulder #4 closed 9:00 PM

Update 1

Time: July 10, 2015; 12:00 AM
East lane #2 closed 12:00 AM
East lane #3 closed 12:00 AM
East shoulder #4 closed 12:00 AM

Final Input

End Time: July 10, 2015; 4:58 AM
All Travel Lanes Clear: July 10, 2015; 4:58 AM; 7 hours 58 minutes
Scene Clear: July 10, 2015; 4:58 AM; 7 hours 58 minutes
Event duration: 7 hours 58 minutes

H1. Hypothetical Incident 1

Incident Location

Initial Input

Start Time: May 2, 2015; 12:31 PM
Incident - Vehicle Accident;
I-66E; At mile marker 61.5;
2 vehicles; 0 injuries; 0 fatalities
East lane #3 closed 12:39 PM
East shoulder #4 closed 12:39 PM

Final Input

End Time: May 2, 2015; 12:44 PM
All Travel Lanes Clear: May 2, 2015; 12:44 PM; 1 hour 13 minutes
Scene Clear: May 2, 2015; 12:44 PM; 1 hour 13 minutes
Event duration: 1 hour 13 minutes

H2. Hypothetical Incident 2

Incident Location

Initial Input

Start Time: May 6, 2015; 4:11 PM
Incident – Spilled Cargo;
I-66E; At mile marker 62.20;
1 vehicle; 0 injuries; 0 fatalities
East lane #2 closed 4:25 PM
East lane #3 closed 4:25 PM
East shoulder #4 closed 4:25 PM

Final Input

End Time: May 6, 2015; 5:30 PM
All Travel Lanes Clear: May 6, 2015; 5:30 PM; 1 hour 19 minutes
Scene Clear: May 3, 2015; 5:24 AM; 1 hour 19 minutes
Event duration: 1 hour 19 minutes

H3. Hypothetical Incident 3

Incident Location

Initial Input

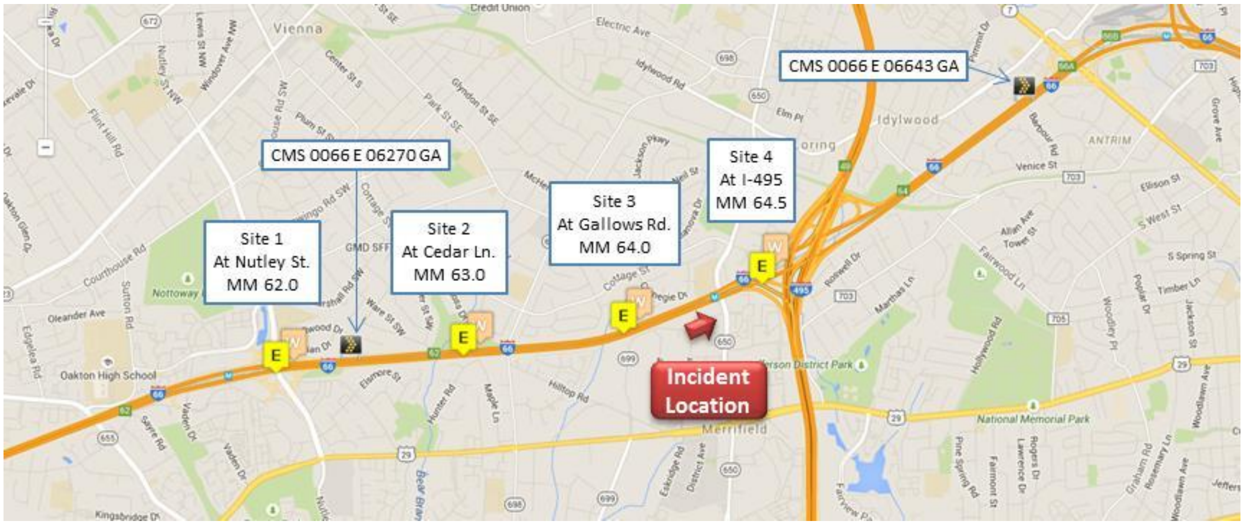
Start Time: May 15, 2015; 12:11 AM
Incident – Car Fire;
I-66E; At mile marker 63.20;
1 vehicle; 0 injuries; 0 fatalities
East shoulder #0 closed 12:11 AM
East lane #1 closed 12:11 AM
East lane #2 closed 12:11 AM

Final Input

End Time: May 15, 2015; 2:01 AM
All Travel Lanes Clear: May 15, 2015; 2:01 AM; 1 hour 50 minutes
Scene Clear: May 15, 2015; 2:01 AM; 1 hour 50 minutes
Event duration: 1 hour 50 minutes

H4. Hypothetical Incident 4

Incident Location



Initial Input

Start Time: May 29, 2015; 8:35 PM
Incident – Pavement Failure;
I-66E; At mile marker 64.20;
0 vehicle; 0 injuries; 0 fatalities
East lane #1 closed 8:35 PM

Final Input

End Time: May 29, 2015; 11:30 PM
All Travel Lanes Clear: May 29, 2015; 11:30 PM; 2 hour 55 minutes
Scene Clear: May 29, 2015; 11:30 AM; 2 hours 55 minutes
Event duration: 2 hours 55 minutes

H5. Hypothetical Incident 5

Incident Location

Initial Input

Start Time: June 6, 2015; 11:11 AM
Incident – Overturned Vehicle;
I-66E; At mile marker 65.20;
1 vehicle; 0 injuries; 0 fatalities
All lanes closed 11:11 AM

Update 1

Time: June 6, 2015; 2:00 PM
Incident – Overturned Vehicle;
I-66E; At mile marker 65.20;
1 vehicle; 0 injuries; 0 fatalities
East Lane 1 Open: 2:00 PM
East Lane 2 Open: 2:00 PM

Final Input

End Time: June 6, 2015; 2:31 PM
All Travel Lanes Clear: June 6, 2015; 2:31 PM; 3 hours 20 minutes
Scene Clear: June 3, 2015; 2:31 PM; 3 hours 20 minutes
Event duration: 3 hours 20 minutes

Appendix E – Post-Incident Survey

Name: ______________________ __________ Incident No.: _____________

For the incident that you just input into the VDMS system, answer the following questions:

1. Please rate on a scale of 1-5 (with 1 being not useful and 5 being very useful) **how useful the VDMS system was** compared to the DMS system:

Providing additional units of information	1	2	3	4	5
Providing relevant information to vehicles	1	2	3	4	5
Preventing irrelevant information	1	2	3	4	5
Geographic Location Options	1	2	3	4	5
Ease of Operator Use	1	2	3	4	5
Quicker Time to Post Message	1	2	3	4	5

Comments:

2. **Please rate the overall quality of the message using the VDMS system, compared to the DMS system.**

Poor Fair Good Very Good Excellent

Comments:

3. **For this incident, please circle which system (either VDMS or DMS) was more appropriate. Please explain why.**

DMS VDMS

Comments:

Appendix F – Exit Survey

Name: ___________________________________

1. On a scale of 1 - 5, with 1 being difficult and 5 being easy, **how easy was the VDMS system to use, overall?**

   1 2 3 4 5

2. On a scale of 1 – 5, with 1 being difficult and 5 being easy, **which aspects of the VDMS system were most difficult to use, compared to the existing DMS system?**

Selecting Location of Incident	1	2	3	4	5
Selecting Location of Message	1	2	3	4	5
Creation of Message	1	2	3	4	5
User Interface	1	2	3	4	5

   Comments:

3. **For each of the following features, which system (either DMS or VDMS) did you feel is more efficient? Please circle one (or both).**

Criteria	DMS	VDMS	Comments
Number of Units of Information			
Customizable Messages			
Relevant Information to Motorists			
Flexibility in Selecting Geographic Locations			
Ease of Operator Use			
Time to Post Message			
Other – please specify			

Comments:

4. **As an operator, what benefits do you feel the VDMS system provides to "motorists" that the current DMS system does not?** Please circle as many of the options below that apply, and explain why.

   Receiving more relevant (detailed) information

   Receiving messages at a more appropriate location

   Less distracting messages

   Receiving message in time

   Comments:

5. **As an operator, do you think VDMS could be incorporated into the current DMS system? Why or why not?**

6. **Please provide any additional comments about your experience in the space below. Be sure to reference a specific incident, if applicable.**