Quantifying Cost Savings of Connected Vehicle-Enabled Applications: Virtual Dynamic Message Sign System Case Study

Alona Green

David Recht

Hyungjun Park, Ph.D.
Senior Scientist
University of Virginia Center for Transportation Studies
351 McCormick Road, PO BOX 400742
Charlottesville, VA22904-4742
Phone: 434-924-1651
Fax: 434-982-2951
E-mail: hpark@email.virginia.edu

Brian L. Smith, P.E.
Professor and Chair
University of Virginia
Department of Civil and Environmental Engineering
Thornton Hall 351 McCormick Road
Charlottesville, VA22904
Phone: 434-243-8585
Fax: 434-982-2951
E-mail: briansmith@virginia.edu

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ABSTRACT

The provision of real-time traffic information to drivers on roadways is a necessity, and has been done so mainly by traditional Dynamic Message Signs (DMSs). However, such systems have considerable costs for equipment purchase, installation, maintenance, operation, and so on, and potentially can be distracting to drivers. With the emergence of connected vehicle technologies that enable wireless communications between vehicles and the infrastructure, the Virtual Dynamic Message Sign (VDMS) system was developed as an alternative to the traditional DMS system. 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. As a result, the VDMS system has potential to significantly reduce the costs associated with traditional, hard-wired DMSs while carrying out comparable tasks. With this background, this paper investigates how much cost savings can be achieved by developing and using the VDMS system as opposed to the traditional DMS system. The results show that, during the 15-year life cycle of eight DMSs at the two-mile study site on I-66 in Northern Virginia, the VDMS system costs only $1,010,000 while traditional DMSs need $5,724,828.75.
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INTRODUCTION

Background

In modern nations, the widespread use of personalized mobile devices has increased the capabilities of advancements and progress towards the development of new technology that enhances daily life. The use of mobile devices to enhance the daily travel to and from a destination is a growing trend, as new advancements allow for advanced traveler information to ensure timely travel and to promote decision-making for the driver. This growing need for motorist information allows for developed research in Advanced Traveler Information Systems (ATIS) and creates an impetus for the creation of related technology in this field. One of these advancements, known as Dynamic Message Signs (DMS), are devices, both permanent and portable, that transmit information from an operator to the traveling public about different events and warnings in the nearby area. New research proposals that would help advance current ATIS infrastructure, such as Virtual Dynamic Message Signs (VDMS), are currently in the process of being researched, not only for their effectiveness, but also for their economic feasibility in comparison to the existing traditional DMS systems. VDMS technology would allow for the information that is current transmitted on portable and fixed DMS to be wirelessly transmitted through Connected Vehicle (CV) equipment and smartphone applications to enable a wider range of communication, while also having a range of benefits of improving traffic congestion and reducing the need for costly roadside infrastructure.

Purpose and Motivation

The limitations of available motorist information is present with the existing modern technology, as the capability of traffic management is greater than the availability of traveler information, due to not enough detailed information, high infrastructure cost, and lack of updated and accurate information. These disadvantages pave way for the research and funding into new CV technology that will help reduce travel times, increase traveler information, and to increase the availability of such information. In addition to this, VDMS specifically would allow for a series of other assumed benefits, such as the reduction of driver distraction, braking, emissions, accident costs, and vehicle operation costs. However, the economic and environmental extent to which these impacts will have an effect, will ultimately depend on the driver’s personal preference and decision-making ability.

Research Objective

The specific objectives of this paper include to:

- Calculate the costs for the proposed VDMS system and traditional DMSs, including device purchase, installation, operations and maintenance, etc.; and
- Compare the calculated costs to determine how much cost savings can be achieved.
LITERATURE REVIEW

Traditional Dynamic Message Signs

Dynamic Message Signs (DMS) are traffic control devices that display various warnings and alerts to drivers on a roadway. Although DMSs come in two forms, permanent or portable, most fixed DMS are most often mounted on steel truss systems that span across all lanes of a highway and portable DMS are used on arterial roads. According to the Manual of Uniform Traffic Control Devices (MUTCD), DMS systems have a variety of established uses to advise the driver of unexpected traffic and rerouting situations. Information sources, such as: Road Weather Information System (RWIS), Closed Circuit Television (CCTV), Environmental Sensing Stations (ESS), or any kind of Roadside Detection (RS-D) can also collect data for displaying information. Typical uses of messaging systems include: incident management, route diversion, adverse weather advisories, notice of special events, lane or ramp control, notice of travel times, speed control, or destination guidance (USDOT).

With the frequent use of DMSs around the nation, there are also consequences or potential issues that arise, mainly due to the fact that DMSs provide information in a text form. In a study performed by Haghani et al. (2013), roadways that implement DMS systems during emergencies, a noticeable speed reduction is experienced, mostly due to drivers braking in order to read the signs. In fact, the study suggests that roadways experienced the most speed reduction with danger/warning messages in comparison with the other types of warnings. When DMS systems post advisory messages, such as work zone construction, studies done by Li et al. (2010) show that driver speeds significantly reduced when a portable DMS was used, in comparison to none being present or turned off, which verifies the impact DMS systems have on traffic flow. Another major issue with DMS is the legibility distance, or the maximum distance travelers can identify a message. This distance has several factors that influence the legibility of the sign, including: roadway curves, shoulder sign locations, and side visibility. Another prevalent issue for DMS systems is the subjective messages, which can be interpreted in different ways by drivers, especially by motorists who speak English as a second language. In a study done by Dudek et al. (2005), driver responses were observed with different dynamic effects seen on DMS systems in comparison to a static message. Although there was no recorded difference in average reading time between the flashing and static-one phase three-line messages, a flashing message has detrimental effects on message comprehension for drivers unfamiliar with this mode of display. The average reading time for one-phase, three-line messages with one flashing top line was also significantly longer than that of static messages.

Funding of Traditional DMS Systems

In addition to the issues presented above, a more significant issue with traditional DMS systems would be that they are very expensive to implement due to their high installation and maintenance costs, most notably the full-size, permanent DMS systems. When investigating costs, there are a variety of aspects to consider, including: initial capital cost, lifetime electrical cost, lifetime maintenance costs, storage and transportation of signs, and the life cycle of the sign itself. For example, in Seattle, the state government’s budget include an annual maintenance budget of $6.8 million for 2010 and about $3.8 million for replacement values of antiquated DMS systems. Mounce et al. (2006) conducted a nationwide survey that interviewed multiple leaders from transportation boards from different states. As a result, it was observed that many states fund the installation and maintenance of DMS systems through the Congestion Mitigation and Air Quality (CMAQ) Program, whose main purpose is to fund transportation projects or programs that contribute to the maintenance of air quality standards and relieving traffic congestion (FTA). Every year, over 2.2 billion (USD) is appropriated to different states to achieve these
air quality standards, and thus, with the installation of different DMS systems on highways nationwide, traffic congestion can be relieved during peak hours through route diversion (VDOT). As a result of the CMAQ program, most DMS systems are installed in locations with high traffic volumes or within an advanced range of a major alternate road decision point.

**Connected Vehicle Technology**

Connected vehicle (CV) technology has the capacity to transform intelligent transportation systems through the creation of interconnected wireless communication networks. The overall concept of CV technology is still relatively new, and thus, most of the existing CV systems consist short range communications. However, with the developing research into CV technology, a series of quantifiable benefits will be produced in the areas of safety improvement, congestion mitigation, and emission reduction. For example, CV technology will allow for the reduced need for traveler information system infrastructure, reduced need for traffic monitoring infrastructure and software, reduced work zone accidents, and reduced crashes and fatalities. However, major rural areas may also have a slower progression into the acquisition of CV technology due to a typical lower amount of allocated government funds and lower population densities, and thus, major cities will have priority consideration.

With the installation of CV technology, there are also a series of stakeholders necessary to ensure the successful operation of the system. For example, a transportation agency, must provide infrastructure and data to support the CV environment, such as: roadside equipment (RSE), interfaces from RSE to roadside transportation equipment, supporting roadside infrastructure (poles, mounting, power sources), and network information services. In addition to this, the motorist must also have a vehicle equipped with the CV technology (with support from the vehicle manufacturer) and a personal mobile device. The success of the rise of CV technology is highly dependent upon the cooperation between companies, the state governments, and the citizens that use the roads themselves. CV technology will not have a beneficial impact unless both vehicle and infrastructure have been built and equipped. However, the Office of Intelligent Transportation Systems currently aims to create interoperable connected vehicle services and networks for both vehicles and infrastructure.

Currently, a form of wireless communication in transportation applications, known as Dedicated Short Range Communication (DSRC) is used for the purpose of motor safety. Inside CVs, onboard equipment (OBE) can be used as transceivers. OBE also provides the communication line between vehicles and RSE and to other nearby vehicles. RSEs can be mounted at a variety of locations, including intersections and along the road that provide interface to vehicles within their range. RSEs are composed of a radio transceiver, an application processor, and an interface to the V2I communication network, along with a GPS unit. By connecting to the communication network, it can send private data to and from the other equipment. In the future, through CV research and funding, highways nationwide can anticipate increased safety, increased mobility, and increased cost savings in terms of the reduction of injuries and traveling delays.

**VIRTUAL DYNAMIC MESSAGE SIGN SYSTEMS**

**VDMS Description**

Virtual Dynamic Message Signs (VDMS) are similar to traditional DMS in that they both inform drivers and passengers of upcoming situations and warnings, but is accomplished through different forms. With VDMS, a software interface can be created and implemented within a traffic network, which allows the installed technology to transmit and receive data at set intervals. Messages can be delivered through various forms of communication (i.e. smartphones) and can be accessed in a larger range in comparison to
the small proximity range of a visual, fixed or portable traditional DMS. VDMS can also be used to track and update real-time traffic conditions to ensure that the information transmitted to other vehicles is updated and accurate. A conceptual diagram of VDMS can be seen in Figure 1 below.

VDMS also has the potential to improve traffic maintenance and flow by broadcasting messages, which are translated into an audible message, then read to individual drivers in their vehicles. By enhancing traffic technology by the inclusion of VDMS, the Department of Transportation will be able to successfully deliver larger, more specific messages to vehicles, rather than short and subjective advisories. In addition, the installation of these systems will also reduce the need for speed reduction, as VDMS is not dependent upon range of sight and legibility distance. The wide availability of technological devices and the progressive development of connected vehicles provide for huge opportunities for advanced traveler information more accessible without the need for outstanding infrastructure costs, and is done so in a flexible manner that is insusceptible to visual or geographic constraints. Lastly, the location-based information could deliver more relevant information through a wider area of proximity with only marginal cost and reduced driver distraction.

FIGURE 1: Conceptual Diagram of the Virtual Dynamic Message Sign System.
**VDMS Cost Estimation**

In comparison to traditional permanent DMS systems, VDMS are significantly less expensive to implement and maintain. Although both systems have upfront capital costs, the reduced need for VDMS to have and maintain physical hardware reduces the costs greatly. With individual states saving upwards of hundreds of millions of dollars during the first year of implementation, other infrastructure projects can be funded with excess finances that have significant impacts upon the safety and mobility of motorists.

**VDMS Usability and Feedback**

According to a study done by Dalton et al. (2013), participants demonstrated a higher level of recognition and retaining directional memory through the use of spoken instructions, but was most effective in a mixed-method approach, of both audio and visual stimulation. For example, when auditory directions were made more complex, participants performed better when there was a visual reference accompanied with the verbal directions. Lastly, the use of in-car route guidance information reduces the overall demands on motorists that navigate new routes. Driel et al. (2005) observed that drivers prefer being well informed about oncoming incidents and in order to help the driver adjust their speeds or seek an alternative route. The study also suggests that the respondents preferred a system that would give support in critical situations, such as fatal crashes and reduced visibility. There is a strong interrelationship between DMS and Advanced Traveler Information System (ATIS) strategies, and through observations done by Chiu et al. (2007), it is seen that joint deployment of both strategies is more cost-effective and efficient than launching them singularly, but is also dependent upon other factors, such as: demand, DMS response rate, incident characteristics, and network structure.

With the development of a VDMS system, it is vital that usability tests must be used that help aid product development and deployment. In studies done by Crosby et al. (1993), by identifying a correct audience, designing and implementing appropriate tasks, and analyzing and reporting their results, the tested products should be more user-friendly with appropriate repeated feedback throughout the development of the suggested product. Pereira da Silva (2003) observes that the main reason for the rise of driving electronic systems development corresponds to necessity for security, as human factors are the main cause of accidents, and these systems seek to reduce human error in information processing required by overly complex traffic conditions. These types of technologies aim to reduce the strain for a human’s mental workload. To ease concerns of distracted driving, studies done by Hatfield et al. (2007), suggest that there is a minimal impact experienced by drivers when listening to audio materials. In comparison to this, the study done by Kelly et al. (2005) suggests that interaction with the existing 511 travel information systems has the same performance effects and risks as a cell phone conversation, thus increasing accident risk by three to four times more likely due to driver distraction and less awareness of surroundings. Therefore, a hands-free interface, such as the one that would be provided for by the implementation of a VDMS system, would should an anticipated safety benefit.
METHODOLOGY

In order to make this study of value, quantifiable data must be calculated and measured to demonstrate the potential benefits from integrating a virtual DMS system into existing infrastructure. The new VDMS system will be analyzed in a method that is identical to assessment of the existing DMS system in order to make a direct cost comparison. Overall, this analysis will be conducted using a “test area” of which about two miles of I-66 will be used for the cost analysis, and its results will later be scaled to a broader, generalized cost analysis for all of Virginia under the same cost assumption. A majority of the cost estimates for existing traditional DMS are a result of extrapolated averages of actual or estimated costs published by various Departments of Transportation from different states. The overall cost estimate for the VDMS systems will be based off conceptualization of the ideal average overall costs.

Constraints

The introduction of VDMS systems through integration into traditional systems promotes a series of constraints that must be addressed when analyzing the disadvantages of a certain project. For example, one major constraint is the issue of funding and market penetration, as new technologies that are introduced in comparison to existing traditional systems, often take longer to implement due to high initial capital costs. Another major constraint with the introduction of VDMS systems is the ease of operation for floor operators that currently work at Department of Transportation. Also, with the introduction of new technology, it may take years for state governments to provide funds for the installation of these new systems. Implementation of VDMS systems involves cooperation between both infrastructure and connected vehicles, and without enhanced deployment of these technologies, it may be difficult to justify the benefits of the deployment of VDMS. Therefore, if VDMS systems can find a way to easily integrate into existing systems, without creating extra tasks for an operator to handle, would be highly beneficial. Therefore, this study assumes full-scale implementation of connected vehicle technology (i.e. RSEs) as mandated by state governments for general safety benefit, and thus, will not be included in the cost for VDMS.

Cost Analysis

Cost analysis can be used to help regulate the decision-making process, but the results should not produce boundaries, but rather, create justification. The results from the analysis, along with public input and product feedback, can be used to analyze monetized and non-monetized impacts of the decision as well. Investment into transportation planning will eventually turn into direct, positive impacts for the project, but must first be estimated in physical terms, then translated into corresponding monetary values. Such values, such as: vehicle operation cost, emission reductions, accident cost, and value of travel time, can have monetary values, but since VDMS systems are still in theoretical production, these values cannot be calculated directly into a quantifiable amount.

For both the proposal and the base plans, the construction and maintenance costs will be estimated according to the anticipated year the expenditure will begin (2015). In the last stage of planning, an evaluation of the total costs will be calculated in order to obtain a cost ratio and to determine the best course of action. Total costs for both the test area and statewide within Virginia will be calculated in order to estimate total amounts of saved finances. Under the assumption that an operator can operate eight signs at once, it is then assumed that with the statewide total of 190 permanent DMS signs, there will be a total of 24 operators, and therefore, the associated salaries will also be taken into account for cost estimation.
Case Study: I-66 in Virginia

According to the Virginia Department of Transportation, the I-66 analysis area has the highest number of crashes and fatalities than any other major highway within the state. Between the years 2008-2010, there have been 1366 total incidents of crashes, with three resulting in fatalities. Two sites that exhibit congested traffic patterns will have two miles of roadway examined for analysis. Also, in order to begin the analysis, there are a series of global assumptions that must be made in order to proceed. According to the Virginia Department of Transportation, the Richmond area receives about $7,967,893 USD for fiscal year 2015 from the federal CMAQ program, and over the course of 2015 to 2020, it can be estimated and assumed that the Richmond area will receive about $49 million in CMAQ funding (VDOT).

Site 1:

This site was chosen because in the 2013 Virginia Department of Transportation annual report, the VA-28 Interchange where Route 28 meets I-66 was named as a major point of congestion. According to the report, the off-ramps from I-66 are projected at a Level of Service (LOS) ‘F’ during peak periods of travel due to short acceleration lanes, which causes poor merging operations. From southbound to eastbound movement, traffic is accommodated by a left turn phase at a signal, but the demand exceeds the capacity, and thus, promotes traffic generation (VDOT). Currently, eight traditional DMS signs exist within the site location.

FIGURE 2: Site location 1 for case study with highlighted DMS locations.
COST ANALYSIS

Although traditional DMS systems are funded underneath the CMAQ program, it is assumed in this research scenario that there is no federal funding to support the deployment of CV, DMS, and VDMS technology to ensure an unbiased analysis. The installation of VDMS can be accomplished through a series of public-private partnerships (PPP), which are arrangements made between public (i.e. governments) and private sectors, in which private service goods are used to benefit the public.

One of the biggest challenges facing the advancement and implementation of CV technology is the financial implications behind the roadside infrastructure. Although CV technology has been proven to increase safety and mobility on roadways, it can only reach its full capabilities and potential if public and private partners occur that involve state governments, vehicle manufacturers, electricity companies, and telecommunication companies. Lastly, the correlated issue of gaining public confidence in these rapidly developing technologies is also a challenge that must be faced to ensure the success of CV and VDMS technology in the United States. Successful integration of virtual DMS data systems offers relief for congestion management, as the CVs will continuously broadcast location, speed, and other vehicle-related data. These sets of data are based on real-time data with present traffic conditions and are more detailed and accurate than current systems (i.e. Waze, radio traffic reports, internet traffic reports, etc.).

Maintenance and Operations

For fixed DMS systems, there are a variety of components necessary for the completion of its construction. For example, permanent DMS systems need concrete foundation, steel gantry structure, message sign panel, and a control cabinet that allows for communication (physical or remote) through a computer (USDOT). Maintenance for fixed DMS systems also vary by time periods, as weekly maintenance consists of a communication and operations test. However, annually, technicians may also check ventilation fans, inspect sensors for obstruction, intrusion, leaks, and corrosion. Portable DMS systems usually consist of a message sign panel, a control system, a mount, and a power source. Maintenance for portable DMS systems are similar to fixed DMS systems, with the addition of a weekly battery voltage check, monthly check for tire pressure, and an annual lubrication of hinges and locks.

Key Parameters

Key parameters are used in order to convert estimates into monetary values and provide values that are accurate and reflect monetary values over multiple years in the future. In this analysis, it is assumed that the discount rate, or the real inflation-adjusted rate, its subjected to be 7%, as recommended by the White House Office and Management and Budget. The base year for this analysis is 2015, so for future analysis, the dollar values will reflect values similar to those future time periods. In addition, the average lifetime of a traditional DMS sign is approximately 15 years, so this project time horizon will span from calendar year 2015 to 2029.