PROTOTYPING AND EVALUATING A SMARTPHONE DYNAMIC MESSAGE SIGN (DMS) APPLICATION

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

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Disclaimer

Connected Vehicle/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

Traveler Information Systems are designed and operated by transportation agencies to provide travelers with real-time traffic information, enabling them to make better travel decisions. One of the most commonly used ways to provide real-time, en route traveler information to motorists is through Dynamic Message Signs (DMSs). Despite their effectiveness, they are costly and limited in terms of the amount of information they can deliver. The wide availability of smart mobile devices can provide traveler information through in-vehicle devices (without incurring huge infrastructure costs) and (in a more flexible manner) to selected individuals and locations without geographical constraints. Research was conducted to comprehensively develop and evaluate this concept and a summary of tasks and findings is presented below.

First, this research proposed the concept of a Virtual Dynamic Message Sign (VDMS) system utilizing a smartphone-based application to demonstrate and summarize user experience for future deployment. The user survey revealed a positive attitude among participants toward a VDMS system in terms of both usefulness and satisfaction; the average ratings were −0.90 and −0.81 respectively on a −2 to 2 (Totally agree to Totally disagree) five-point Likert scale. The survey also indicated that most drivers (81.0%) perceived VDMS as a safer way to receive information. Many drivers (66.7%) also felt more comfortable receiving an audible message from a VDMS system rather than a text message on a DMS. The results indicate great user acceptability and the potential for such systems to be deployed by public agencies in the future.

This research also aimed to address the question of whether a VDMS conveys information at least as effectively as existing DMSs. A mixed, repeated-measure experiment was designed using a driver simulator to examine (1) the impacts of driver age, (2) information transmission mode, (3) amount of information, and (4) driving complexity on message comprehension, distraction, and perceived difficulty.

Forty-two people were recruited and each of them participated in a test under different combinations. Participant performance was measured in terms of message comprehension, distraction, and self-reported message difficulty level. Results revealed that VDMS generally performs better than DMS across different amounts of information, under different driving conditions, and regardless of driver age. VDMS proved significantly better than DMS in message comprehension under relatively complex conditions. It reduced reaction time to unexpected stimuli (as measured with a reduced time-to-brake of 0.39 seconds), and made the same messages easier to process and retain for drivers than DMS.

Based on these results, it is recommended that transportation agencies give careful consideration to VDMS as a future strategy for delivering public traffic information in a connected vehicle environment.

Acknowledgements

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Introduction

Background

The purpose of Traveler Information Systems is to provide travelers with real-time traffic information, enabling them to make better travel decisions. Relevant information may include locations of incidents, work zones, weather, road conditions, and lane closures, etc. This study examined two types of traveler information: time provision and information sources. For time provision, categories included pre-trip information and en route information. Although information sources can be both public and private, this study focused on public, en route traveler information provision.

Public Traveler Information

Public Traveler Information refers to data provided by public agencies, such as state Departments of Transportation (DOTs) and Traffic Management Centers (TMCs). This information is made available through different channels: Dynamic Message Signs (DMSs), 511 websites, the 511 telephone number, 511 smartphone apps, and Highway Advisory Radio (HAR), to name a few.

Among the different dissemination approaches, DMS has been widely used by state DOTs or TMCs to provide real-time, en route traveler information on freeways and arterials. While the DMS has been proven effective, it has many limitations. First, the amount of data that can be displayed on a DMS during the time period when drivers can see the message clearly is very limited, usually allowing only 8 seconds for three information units on each screen phase. Second, reading a DMS distracts from the driving task. This can be seen in many locations where monitoring sensors reported a reduction in speed due to drivers braking to read DMS messages [1]. Such distraction potential also forces DOTs to use short messages on the DMS, which hampers the objective of informing travelers.

Another limitation exists because DMSs are fixed assets. They are expensive and can only inform travelers at the location where they are installed. Lastly, a DMS is typically placed roadside or overhead for all passing traffic. Since the TMCs have no individual information about travelers, they can only provide the same information to everyone, no matter whether they need it or not. This further increases the distraction to travelers who do not need the information. Future deployments should consider innovative information delivery methods to tackle these problems.

The public sector has established traditions of traffic management, and real-time traveler information is one of its most powerful management tools. Currently, public agencies publish basic traffic information on a daily basis to inform travelers and let them make their own travel decisions. However, public agencies may need to take a more active role in managing traffic, particularly under special emergency conditions. For example, the Virginia Department of Transportation (VDOT) has defined emergency incidents as an occurrence, human or nature-caused, that require public agencies' response, such as weather-related emergencies (e.g., flooding, hurricane), severe incidents, hazardous materials spills (hazmat), and terrorist attacks (see http://www.virginiadot.org for more information).

Public agencies need to make best use of the capacities of existing facilities by providing routing advisories, responding to ensure public safety, and maintaining or restoring traffic movement under emergencies. Currently, DMSs only provide general routing information, such as listing the closure of certain routes or asking all traffic to use alternative routes. This limited information can be traced to the delivery mode of the DMSs, which are deployed at just a few locations and can only provide the same general, one-for-all messages for all travelers.

Private Traveler Information

Private Traveler Information is provided by private companies, such as Google, INRIX, TomTom, and Waze (Google). They provide this type of information through websites and apps on personal devices like smartphones. Private Traveler Information has three unique attributes compared with current Public Traveler Information.

1. **Detailed:** More information can be provided through personal devices, using audio, text, and map display than by using a DMS. Most of the apps can provide the same basic traffic information as the DMS, although it is usually based on data from different sources (e.g., user reports). Also, the personal route guidance provided by these apps is based on current travel times. By comparison, DOTs do not usually provide route guidance on a daily basis, but they will potentially provide route advisories (e.g., alternative route numbers) under emergencies and other special conditions.
2. **Personalized**: Personal devices can pinpoint the attributes of each traveler (location, destination, value of time, and habitual routes) and can customize information accordingly. Since vehicle location and destination are key attributes of en route traveler information, they can only be obtained via personal devices and real-time communication with a Web-based infrastructure. By contrast, current public information modes such as DMS are limited, but in the future they can potentially maximize their attributes.
3. **User-oriented**: Influenced by private companies' business models, Private Traveler Information/route guidance has been designed to optimize personal travel experiences. This includes help in selecting the most direct routes and those with the shortest driving times for each user. Public agencies focus only on managing traffic and making the best use of existing facilities and fixed assets.

This study focused on public, en route traveler information. However, technologies widely used in the private sector (personal devices and wireless communication) can be drawn upon and tailored to develop innovative concepts for next-generation public, en route information.

Research Motivation

As discussed previously, the current public, en route traveler information mode (DMS) is constrained by limitations such as inadequate detail of information, distraction to driving tasks, one-for-all message delivery (information irrelevant to many travelers), and high infrastructure cost. Thus, we need a new channel to more effectively deliver public, en route information. The new channel needs to be able to provide more-detailed information, including traditional basic information (e.g., location and time of incident, congestion, work zone, and segment travel time). It must also enable more advanced traffic management strategies when necessary, such as routing advisories under emergencies that target each individual driver based on their current location. Also, the new channel must be able to increase the public's comprehension of traffic information and reduce driver distraction. This, in turn, can permit the provision of more-detailed information. Lastly, the new approach needs to be cost effective without relying on a huge infrastructure investment, and must also be flexible and scalable for wide deployment.

This study proposes the concept that, as information and communication technologies advance, traffic messages could be delivered to each driver through in-vehicle devices. These devices could be smartphones and/or onboard units of connected vehicles (CVs). This new concept is referred to as a Virtual Dynamic Message Sign (VDMS) in this study. It is a truly "mobile" application and provides real-time, en route information, the type meant to be used while a driver is driving. This distinguishes it from current 511 applications that explicitly state that they are to be used only when the vehicle is not in motion.

Figure 1 demonstrates the Virtual Information Zone, a feature of the VDMS. A Global Positioning System (GPS) monitors the driver's location using the in-vehicle device. The device sends location information to the server, which matches the coordinates provided by the GPS to a real location on the server map. When the driver moves within range of a predefined information zone or link (i.e., represented by latitude and longitude, as shown in Figure 1), the data associated with this zone are presented to the driver via an audible message. At the server end, an application retrieves real-time information from traveler information providers or uses an embedded algorithm to predict and calculate traveler information using real-time traffic sensors.

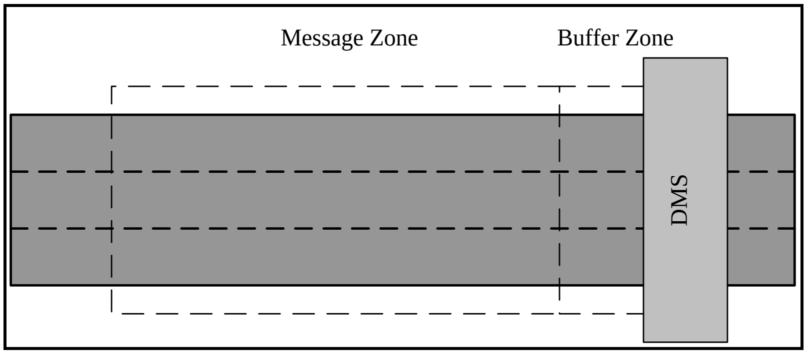

Figure 1. Illustration of the Virtual Information Zone.

Purpose and Scope

This research addresses several gaps in knowledge and strives to answer two critical questions. The overall structure and scope of this study are shown in Figure 2.

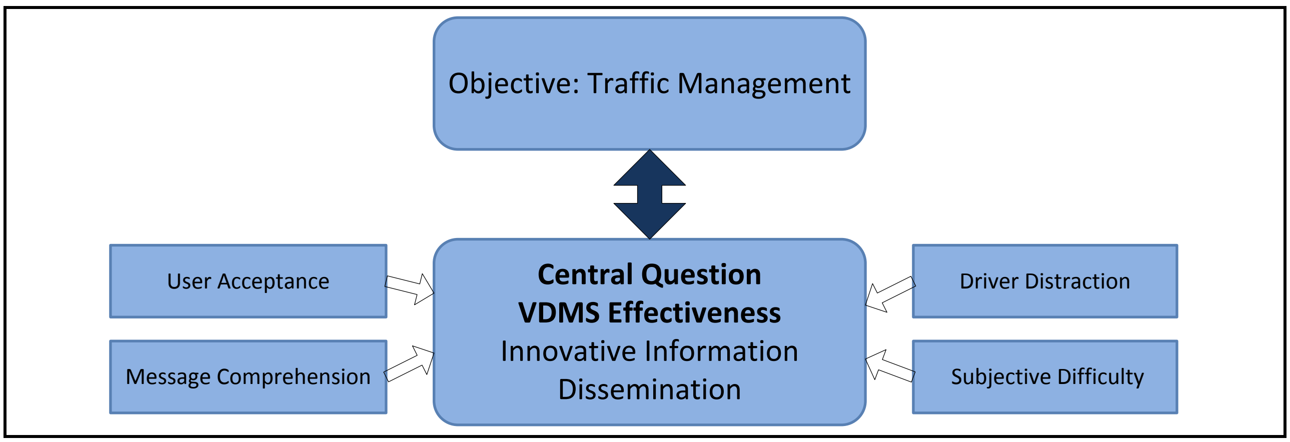

Figure 2. Report structure and scope.

The central question regarding improving traffic management relates to the innovative information dissemination method, VDMS. In order for it to be innovative and productive, two additional questions need to be answered: (1) what will it take to achieve user acceptance; and (2) what human factor issues relate to driver performance when a driver receives messages through VDMS? The first phase of this study prototyped this system to assess its potential acceptance among travelers and their attitudes toward this new technology. The results will help to understand the possibilities and issues to be addressed for future wide deployment of such systems.

Next, due to the differences between drivers receiving audio messages in-vehicle and reading written messages on a roadside DMS, it was necessary to study the effectiveness of VDMS. When a VDMS communicates messages to drivers, will they understand them? Are they distracted by receiving them? This study considered current roadside DMSs as a baseline and investigated whether VDMS would be a viable way to deliver en route traffic messages to drivers with in-vehicle devices.

Research Contributions

This research will produce several major contributions to the state of knowledge. These contributions include:

- Introduction of VDMS concepts and an evaluation of user acceptance/experience via a prototype application. This is one of the first smartphone-based CV traveler information system prototypes for public, en route traveler information.
- Investigation of the effectiveness of VDMS in delivering traffic information in terms of message comprehension, distraction, and subjective difficulty level. Our driving simulator-based human factor experiment provided a deep understanding of how VDMS compared with DMS. Those results can serve as evidence for agencies to deploy such systems in the future.

Literature Review

The literature review was conducted to survey past work on issues related to advanced traveler information systems and dynamic traffic management. The literature was sorted into two categories for this section: (1) traffic applications and user acceptance and (2) driving-related human factors issues.

Traffic Applications and User Acceptance

Traffic Applications

With the advancement of communication and mobile devices, a variety of traffic applications have been developed to improve travel experiences. CV technologies have injected new vitality into the development of various Intelligent Transportation Systems (ITS) applications, such as intelligent cruise control and collision avoidance system. A lot of research has developed and evaluated many CV applications, either using cellular-based smartphones or Dedicated Short Range Communications (DSRC)-based onboard devices.

Smartphone technology and cellular networks (especially 4G/LTE networks) have been well developed and applied to the collection and the dissemination of driver information since the 1990s. Many developers and researchers in recent transportation application development have utilized this technology to produce innovations such as a safety enhancer for bike riders [2], assistance applications for visually impaired pedestrians at intersection crossovers [3], and a green-behavior application [4]. Since DSRC technology development is still in its infancy, most of the relevant research used simulation-based system evaluations. For example, Park and Smith [5] investigated benefits of CV technologies (formerly "IntelliDrive") in lane changing advisory of freeway operations. Lee et al. assessed the sustainability benefits of Cooperative Vehicle Intersection Control at an Urban Corridor [6]. Goodall et al. made use of more-enriched data from the CV environment to improve traffic signal control algorithms [7].

Specifically, this study is interested in traffic applications that provide drivers with traffic information that will aid them in making travel choices. Table 1 lists a few of the better-known traffic applications available in the market and their corresponding descriptions.

Table 1. Lists of Existing Well-known Traffic Applications

Name	Description
511 website and app	Provides real-time traffic information as well as updates on traffic conditions and weather forecasts.
Sigalert	Provides information on current road conditions, speed information, and access to live cameras to aid commuters.
Waze	Relies on user participation for reporting traffic, car accidents, and the presence of speed traps. Once a report is made by one user, other users are able to access that report using the Waze map.
Beat the Traffic	Shows real-time maps of road and traffic conditions for users.
iTraffic	Provides live traffic maps, showing traffic speeds and incidents on major routes for hundreds of cities and suburbs to help you plan your schedule and route.
Inrix Traffic	Provides users with real-time traffic information, traffic-impacting incident information, traffic forecasting, reported incidents, and projected arrival times for Windows Phone, iOS, and Blackberry users.
View2Road	Allows users to view live cameras of certain road locations using iOS and Windows Phone devices.

All applications listed in Table 1 can provide real-time information on travel time, traffic incidents, work zones, lane closures, and road weather conditions using different data sources. For example, state DOT 511 websites make use of both public-sector and private-sector data, The DOTs purchase data from private companies to provide traveler information, while private apps (like Waze) rely heavily on the traffic reports provided by users. Programs like Connected Citizens by Waze enable private companies to have access to traffic data from the public side and thus provide their users with more comprehensive data.

However, these apps, both public and private, should only be used when the vehicle is not in motion. Using them while the vehicle is in motion would raise the level of driver involvement and using them en route would cause great safety concerns.

Evaluation and User Acceptance

Most of the current research has only studied the system effectiveness of various transport telematics after deployment using either simulations or prototypes. While excellent system performance may be sufficient for the technician, it is equally important that the equipment appeals to and is accepted by the vehicle's driver. For many advisory systems, the main issues determining their feasibility are not of a technical nature; instead, they concern the social context for introduction [8]. A prerequisite for the introduction of new in-vehicle technology is acceptance by the public. It is unproductive to invest effort in designing and building an intelligent "co-driver" if the system is never switched on or disabled.

There is no standard way to measure driver acceptance of new technology. A review of the literature shows that there are almost as many methods to assess acceptance as there are acceptance studies themselves, and little development of evaluation methodology exists today. Systems have been evaluated on their pleasantness and usefulness [9], comfort and benefit [10], or the ease or degree of use [11]. Aspects highlighted in the evaluation of the information provided are content, format, reliability, relevance, accuracy, and the effectiveness of the information [11-12]. Acceptance sometimes includes the intention to purchase the system and assessment of the price people are willing to pay (e.g., [10]). Van Der Laan et al. proposed a set of nine questions specifically to assess the acceptance level from the perspective of usefulness and satisfaction and proposed statistical methods for the Likert-scale data obtained from the nine questions [13].

Driving-related Human Factor Issues

Human factors in the driving environment, including scenarios with traveler information, have been studied extensively in the past several decades. Dudek performed a comprehensive review of studies for various real-time traffic message modes before the 1970s, including external visual message (DMS and static signs), in-vehicle visual, and auditory (radio) [14]. However, this study, and earlier ones, only made use of simple evaluations such as a preference survey. They also proposed more questions, especially on human factors, to be answered to guide future public and private message design.

Since then, due to the wide use of DMSs, many researchers have conducted studies on related human factors issues, aiming to understand the best practices of message and display design for better driver comprehension and less distraction. Most of these famous studies were conducted by Dudek and his associates [15-18]. They investigated various aspects of DMS information such as information quantity, font size, flashing lines, abbreviation use, and consecutive portable DMSs.

The tests were performed by using either a laptop or a real-car-based driving simulator. The quality of the information delivery was measured by the drivers correctly recalling the messages, their reaction times, and their stated preferences. Other research made use of real traffic count data or survey data to study the effectiveness of various message display mechanisms. For example, Peeta et al. found different response rates (measured by willingness to divert) for different types of information using a roadside stated preference survey [19]. The results showed that travelers were willing to divert when detailed information was given. Schroeder and Demetsky used detector data from Richmond, Virginia, to estimate diversion rates attributable to different DMS advisory messages; the results showed trends where the usage of particular words in messages proved more effective than others in causing diversion [20]. Xiong and Zhang calibrated a DMS diversion model using driving simulator data combined with real world blue-tooth data that allow researchers and practitioners to transfer the en-route diversion model to other regions based on local observations [21].

In terms of in-vehicle systems, most of the literature focused on in-vehicle route guidance systems, usually used by drivers to optimize personal trips. Literature on the various aspects of guidance systems covers audio message content, visual message display and content, digitized versus synthesized speech, timing of information, location of visual displays, and driver interaction with information devices. Schraagen suggested that the direction of the next turn and the distance to the turn are most essential and street names and landmarks should not be provided since street name signs are sometimes difficult to locate or are completely absent from the road [22]. Roelofs [23] and Srinivasan et al. [24] indicated that recorded speech was overwhelmingly preferred over synthesized speech, although tracking performance, response times, and errors did not indicate any differences between recorded and synthesized speech.

A number of studies compared in-vehicle visual and audio route guidance systems. These studies generally focused on the presentation of information: audio [25]; visual text (symbols, font size, color) [26]; visual maps (orientation) [27]; format for turn-by-turn displays [28] and the combination of either two or three approaches [29, 30].

Most of these studies agreed that the audio system led to less distraction from the driving task. The audio system worked best when the information was simple and short, especially when the driver’s visual system was overburdened. Studies in the recent decade have focused on the human factors issues with advanced technologies (driver interaction) with guidance systems (touch screens and smartphones) [31], and with in-vehicle warning systems in the CV environment [32]. Other studies on human factors issues have also enriched methodology and our understanding of human performance under various conditions of driving, such as the use of cell phones [33, 34], listening to music [35], and the existence of multimedia devices in the car [36].

The effect of driving conditions, simple or complex, has attracted a great deal of attention. When the relationship between mental arousal and driver performance was examined, research suggested that the existence of secondary tasks would not necessarily cause driving performance to deteriorate (usually a measure for distraction level). In fact, drivers sometimes performed better under simple driving conditions (i.e., monotonous driving) [35, 37].

This argument is in line with the Yerkes-Dodson law [38], which posits that the relationship between task performance and arousal can be depicted by an inverted U-shaped curve. When one's arousal level is too high or too low, performance is predicted to be inhibited, while a moderate arousal level is expected to result in higher performance. Interestingly, for monotonous tasks, an increase in mental effort might be expected when the arousal level is below ideal, as well as when the driver feels less alert due to fatigue or boredom, or due to the effort of fighting boredom or fatigue [39, 40]. These findings are especially important to our study, since reading and comprehending messages are needed under both simple and complex driving conditions, and it is necessary to quantify driver performance on both tasks under both conditions.

Chapter 1: VDMS Concepts, Prototype, and User Experience

VDMS Deployment Concepts

Transportation agencies have a unique and important role in providing driver information that will enable the safest and most efficient utilization of existing transportation facilities. Considering the limitations of the current public, en route traveler information mode (DMS), we need a new channel to more effectively deliver en route information. The new channel needs to be able to do two very important things: provide more-detailed en route information and enable more-advanced traffic management strategies. However, the more-detailed information also needs to include traditional basic information (e.g., location and time of incident, congestion, work zone, and segment travel time). The more-advanced traffic management strategies should include routing advisories under emergencies that target each driver based on current location. Also, the new channel needs to increase comprehension of information and reduce driver distraction, which in turn allow for the provision of more-detailed information.

The concept of VDMS proposed earlier meets these needs and overcomes the limitations of current DMSs. This section discusses in detail four functionalities that are critical to the success of next-generation traveler information systems enabled by the VDMS concept. The functionalities discussed below are guided by four criteria: (1) the VDMS should be auditory; (2) the VDMS should be scalable; (3) the VDMS should be customizable; and (4) the VDMS should be available in many locations.

1. **The VDMS should use auditory messages.** DMS messages depend upon line of sight and require user efforts to read the messages. We propose replacing the simple roadside written message with a detailed in-vehicle audio message. First, the audio message will not be restricted by the message length and can provide more information to the driver. For example, instead of basic DMS messages like "FREEWAY BLOCKED | AT [location] | USE OTHER ROUTES," VDMS could provide more details using a human voice audio message. More-detailed messages, such as "Major accident ahead at [location]. Three lanes are closed. Please use other routes," would help drivers make better and safer travel decisions. VDMS could also list potential alternative routes, such as "Please take Exit 50 and use Route 51." Second, the audio message will require much less "active" participation and will enable a true "mobile" application, meant to be used while a driver is traveling. This distinguishes it from current 511 applications that explicitly state they are to be used only when the vehicle is not in motion. Also, drivers will no longer need to be distracted by focusing their attention to read roadside message signs; simply hearing the message will generally be much easier for them.
2. **The VDMS should be scalable.** Since DMSs are fixed assets, each sign is expensive and can only provide information to travelers in a very small geographic region. Thus, they are placed

selectively and can only inform travelers at the location where they are installed. The VDMS is not fixed and can be "built" by defining information roadway segments as new latitude/longitude areas from the server. The cost will become marginal once the infrastructure and user-end devices become mature, and thus they can be placed anywhere in the roadway network. For example, when an incident happens, instead of relying on several fixed DMSs or using a limited number of portable DMSs, DOTs could use VDMS to relay the information to all the relevant links, simply, quickly, and at very low cost.

3. **The VDMS should be customizable based on personal preferences.** Current DMSs all use the same font type, size, abbreviations, and the same display interval for two-phase messages. While these suit most people, they are not the best for all, and they are not even suitable for groups of people with special needs. When drivers cannot read English, current DMSs are not useful. The VDMS can present traffic messages in English, Spanish, and other languages. Other features such as the audio volume, the audio pace, and number of times the same message is repeated should be adjustable to fit the drivers' preferences. Drivers will likely make better choices when they feel comfortable with the information sources; that way, they can receive and understand messages more easily.
4. **The VDMS should be available in many locations**. Today public traffic information applications (the 511 website and smartphone app) usually provide users with information about a region or even a state. No matter where the incident occurs, the users opening the app will be given the same message. Even if new filtering functions were added (e.g., users could input several of their usual routes like "select I-66"), the range may still be too large and the messages may not be relevant to a specific trip. An overwhelming amount of irrelevant information may reduce users' interest and cause them to stop using the application.

   To avoid this problem, VDMS "places" traffic information on selected links or directly in specific areas; that way, travelers will receive the message only when they are on that link or in that area. Furthermore, different messages could be "placed" at one location but only the most appropriate ones would be delivered to a specific driver. The delivered message would be based on the driver's characteristics: destination, value of time, and preferred routes. If a driver is not going to drive near the downstream incident (e.g., his destination is close and he will use the next off-ramp), the incident information would not be provided to avoid unnecessary distractions.

VDMS Smartphone Prototype

A thorough evaluation of VDMS will require a lot of effort and input from various perspectives. The first task is to discover how this new concept will work and to determine travelers' views and levels of acceptance. To accomplish this, we decided to develop a prototype system and ask users to state their opinions in a survey. We compared DSRC capability with that of smartphone technology and cellular networks. While DSRC applications remain in the initial stage of development, smartphone technology and cellular networks (especially 4G/LTE networks) are well developed and have both been applied for collecting and disseminating driver information for a long time. Smartphone technology has been used by many developers and researchers in recent transportation application development (e.g., [2, 3]). Therefore, we decided to prototype and evaluate a smartphone VDMS application. In the prototype application, a traveler's location was monitored using the phone's GPS. When the driver arrived within range of a predefined information area (i.e., in a range of latitude/longitude coordinates), the information was presented via an audible message.

System Architecture

The high-level conceptual diagram of the proposed VDMS is illustrated in Figure 3. It is designed to allow two-way communication between the smartphone and the server. The five main components of the architecture are the client (cell phone), the cellular communication network, the Internet, the server, and the DMS Web service (traffic information sources; shown in Figure 4). The smartphone's location function is activated once the application is turned on, and it determines the location of the vehicle at certain time intervals. These location data, along with time information, are then sent back to the server via the cellular network (the second major component). The cellular network can also be used to provide user position information through cell signal triangulation or the Cell-ID of the base station if the primary means of obtaining this data (i.e., the GPS satellites) is unavailable. The Internet, the third component, is the transit network for application data between the cellular network and the server. The next element of the system architecture, the server, checks the real-time location information of each vehicle and sends the relevant DMS message back to the user/driver. The last element is the traffic information sources, which are responsible for providing real-time traffic messages.

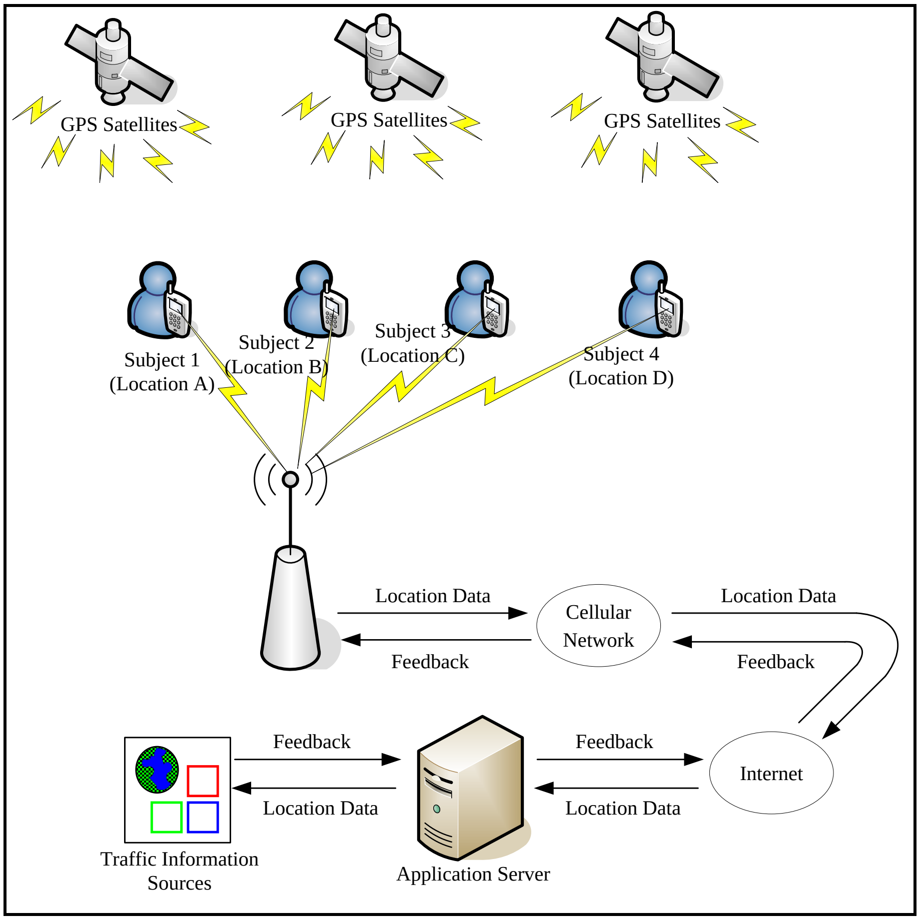

Figure 3. VDMS system architecture.

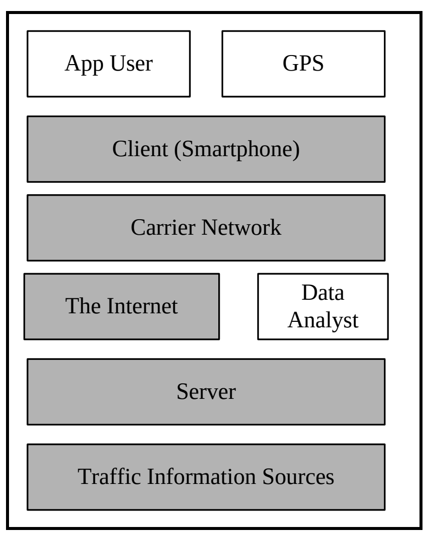

Figure 4. Main system components of VDMS.

Implementation

The VDMS application was developed on the Google Android platform for smartphones (http://developer.android.com/index.html). The app was developed with the JDK 1.6 and Android SDK 4.1.2. The smartphone application located the vehicle on a regular basis and sent this information to the server. After it received feedback from the server, the application converted the text message to audio for the user. Android offers a Text-To-Speech (TTS) Application Program Interface (API) that can be personalized in terms of the language, pitch, and speech rate used when "speaking" to users. The location function used the standard "Location Listener" service provided by Android. The "Location Listener" requested and obtained the GPS information that was used to derive coordinates, speed, heading, and other position and travel data. This technology offers the opportunity to further increase safety and improve upon the current industry-standard method of sending text messages for traffic alerts. The server received, analyzed, and provided feedback for travel data transmitted by the end-user device. An open-source Relational Data Base Management System (RDBMS), PostgreSQL, was used to store and process real-time data. These data included each GPS location, date and time stamp, travel direction, and speed, as well as the closest point on the link generated from the map-matching process.

PostGIS, a spatial database extender, works with the PostgreSQL object-relational database. It adds support for geographic objects and allows location queries to be run in SQL. We made use of PostGIS for spatial analysis, especially in the map-matching process. A server program was developed to match each point it receives to a digital map server (the Northern Virginia Interstates network in this study) to find the exact link where the car is located. Since the network in this study was relatively sparse and contained only freeways and arterials, a simpler mechanism of "snapping" to the closest link was used. Meanwhile, real-time traffic information was requested by the server from the Virginia Traffic and Video Data Sharing Site (VDOT TVD, http://www.vdotdatasharing.org).

The communication between the server and client took place through the 3G/4G/LTE cellular network and the Internet. This "ServerSocket" class in the Android SDK was used and it represents a server-side socket that waits for incoming client connections. A "ServerSocket" handled the requests and sent back an appropriate reply.

User Acceptance and Experience Survey

A focus group user experience survey was conducted to evaluate the developed VDMS traveler information app in order to obtain users' potential attitudes toward the new concept of transportation telematics. Since the experiment network for the prototype VDMS system used the northern Virginia road network, 21 commuters in northern Virginia were recruited through email blast and advertisement. The test network consisted of the northern Virginia freeway system, including I-66, I-495, and I-395. Participants were selected based on a few basic criteria (e.g., possessing an Android smartphone and commuting on the northern Virginia test network daily). After that, each participant was provided with step-by-step instructions (http://people.virginia.edu/~jm7md/vdmssupport.html) to download the app from the Google Play store (https://play.google.com/store/apps/details?id=edu.virginia.cts.vdms&hl=en) and install the app on their personal Android phone. Each participant also received a free car-charger as an incentive to use the app for a relatively long time. Participants were required to use the app for at least two weeks, and then a survey link was sent to each of them to collect data on their acceptance level and experience with the app.

Part I of the survey included three basic demographic questions on gender, age, and education level. Among 21 participants, 13 of them (61.9%) were male and 8 (38.1%) were female. About 14.3% had some level of college education, 38.1% were college graduates, and 47.6% were postgraduates. In terms of age, 33.3% of them were between 18 and 29, 47.6% between 30 and 39, 9.5% between 40 and 49, and 9.5% between 50 and 64. This demographic distribution was generally balanced and demographic variety was suitable for this study. The survey questions can be found in Appendix A.

Part II of the survey included nine sub-questions/items. The answer options were designed to evaluate usefulness and satisfaction to assess the drivers' acceptance of this new application of transportation telematics [13]. Questions rated qualities like usefulness and pleasantness, safety, informational value, convenience and ease of receipt, comprehension of messages, and annoyance. The aggregate survey results are shown in Table 2. The number in each cell lists the number of participants who checked that cell during the survey.

Table 2. Aggregate Results of Nine-item Questions on User Acceptance Level

	Answer Options	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Answer Options**
Score		**-2**	**-1**	**0**	**1**	**2**	
1	Useful	5	11	4	0	1	Useless
2	Pleasant	2	12	6	1	0	Unpleasant
3	Good	0	14	6	1	0	Bad
4	Nice	2	13	5	1	0	Annoying
5	Effective	2	13	5	0	1	Superfluous
6	Likeable	4	12	4	1	0	Irritating
7	Assisting	5	12	3	0	1	Worthless
8	Desirable	3	14	3	0	1	Undesirable
9	Raising alertness	9	10	2	0	0	Sleep-inducing

As recommended by [13], the following steps were adopted for the analysis:

1) For each of the nine questions, individual items were coded from −2 to + 2 from left to right.

2) Reliability analyses were performed. Questions 1, 3, 5, 7, and 9 were used for the usefulness scale. Questions 2, 4, 6, and 8 were used for the satisfaction scale.
3) When reliability (Cronbach's α) was sufficiently high (above 0.65), the per-subject end score for the two scales was computed by averaging the scores on items 1, 3, 5, 7, and 9 for the usefulness score, and averaging the scores on items 2, 4, 6, and 8 for the satisfaction score.
4) The usefulness scale was averaged over subjects to obtain an overall system practical evaluation. The same was done with the satisfaction scores.

Following the above steps, the Cronbach's α was calculated, and the result of 0.93 indicates great reliability of the survey answers. Then, the overall evaluation scores were calculated with the results of −0.90 and −0.81 for usefulness and satisfaction, respectively. On a scale of −2 to 2, the scores imply that, on average, the participants "agree" with the usefulness of the new system and are satisfied with the experience of using the app as an tool to receive en route DMS-like traveler information. Thus, we can conclude that the participants can accept this new type of en route traveler information in terms of its usefulness and satisfaction.

Part III of the survey included 11 questions on user experience. Question 1 and 2 were specific to the functionality of the application, verifying whether or not the provided information is relevant and timely, respectively. The results, as shown in Table 3, indicate that the users generally agree regarding the functionality of the app, and confirm the feasibility of using it for this study. Note that some participants gave low ratings for the two questions. This could be because the app was designed to broadcast information about one mile ahead of the source DMSs. It could also be that the information provided by the DMS could be problematic itself.

Table 3. Survey Results of Question 1 and 2

	1	2	3	4	5
Q5. Was the information provided relevant?	Completely Disagree				Completely Agree
	2 (9.5%)	4 (19.0%)	5 (23.8%)	5 (23.8%)	5 (23.8%)
Q6. Was the information timely?	Really Bad				Really Good
	1 (4.8%)	5 (23.8%)	5 (23.8%)	9 (42.9%)	1 (4.8%)

Question 3 asked participants, "Which message type would you prefer?" The result in Figure 5 implies that participants preferred VDMS audio information three times more than DMS information. Also, very few participants preferred a text message on the phone, probably because participants also understand the inconvenience and safety concerns of reading text messages during driving.

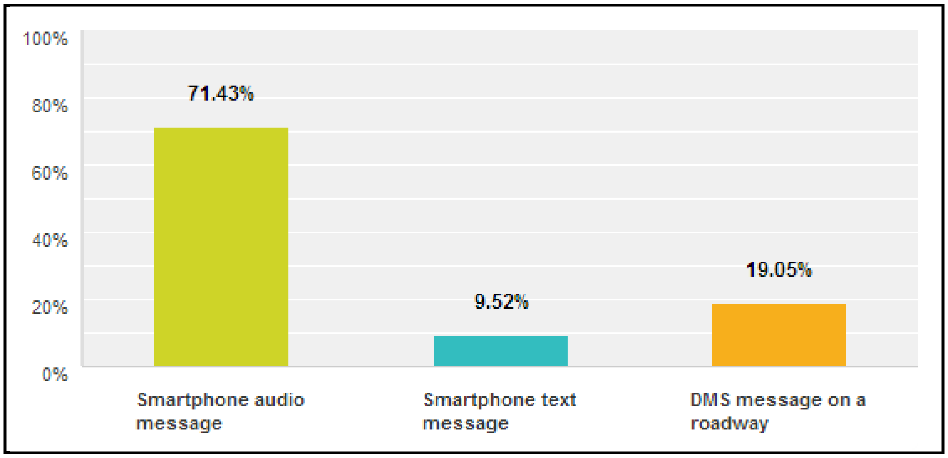

Figure 5. Answers for Question 3.

Question 4 asked participants, “Do you feel it is safer to hear the audio messages on your phone or to read the messages posted on the DMS signs?” The result in Figure 6 clearly demonstrates that most of participants believed VDMS audio messages were a safer way to receive en route traffic information.

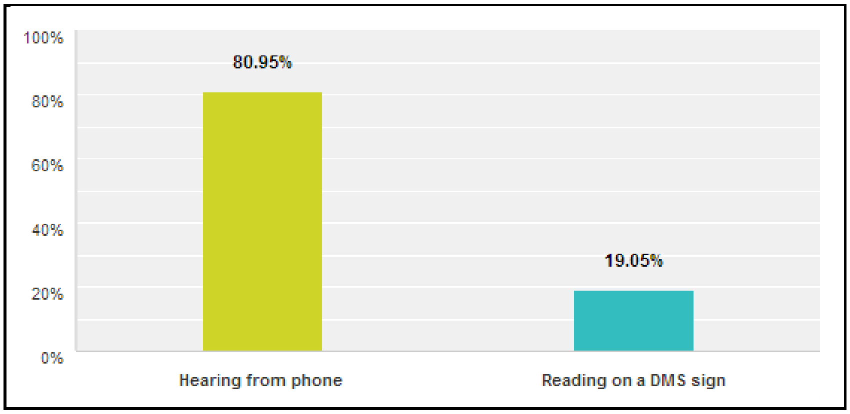

Figure 6. Answers for Question 4.

Question 5 asked about which mode of receiving messages, hearing from a phone or reading on a DMS sign, was more confortable for the participants. The result in Figure 7 shows that twice as many participants felt more comfortable hearing a message from the phone rather than reading one from a roadside DMS sign.

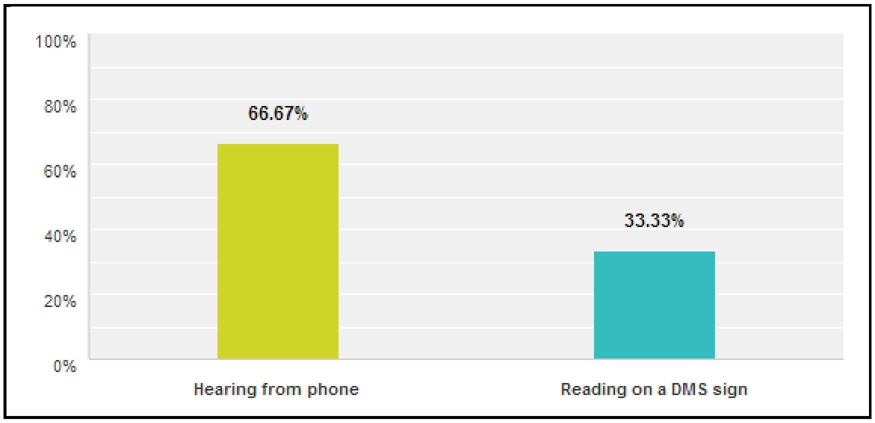

Figure 7. Answers for Question 5.

Question 6 asked participants whether they are more likely to follow suggestions from the audio message sent to their phone or from a message posted on a roadside DMS. It is likely that most of them did not distinguish between the two modes of information, as shown in Figure 8. However, more participants chose VDMS than DMS probably because they consider VDMS a more personal and more trustworthy source of information on which they could rely during their travels.

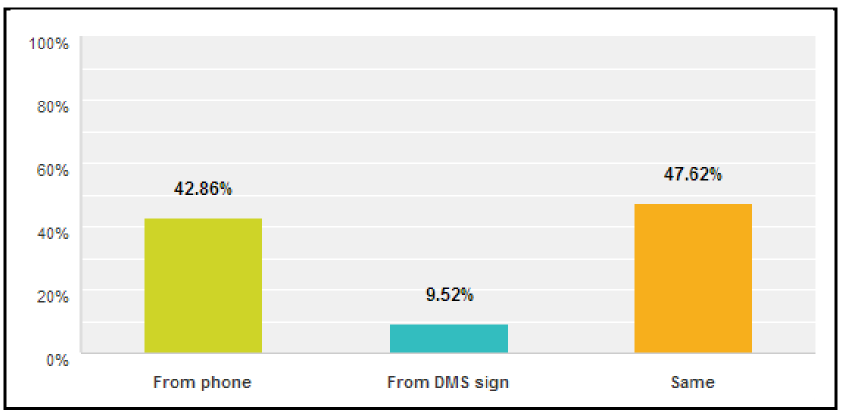

Figure 8. Answers for Question 6.

The subsequent questions asked about opinions on possible future functions and deployments. Nearly 86% of the participants prefer the audio message to be repeated twice. This is an expected result since repetition usually increases users' comprehension of messages. This is also an advantage of VDMS over DMS, which can only be read for a limited amount of time (around 8 seconds) when users are traveling on freeways at 65 mph. Also, 81.0% of the participants prefer receiving messages at more locations than the fixed or limited locations possible with current DMS signs. This preference coincides with the scalability benefits of VDMS.

Since VDMS can potentially provide more information of different types, the next question asked what kinds of information users would like to hear from VDMS. The results are shown in Table 4. The ranking is from 1 to 7 (high to low) and the ranking average is calculated by averaging all the rankings for the specific information type. It quickly becomes apparent that, when more information can be potentially delivered, users prefer more comprehensive information in order to make a better decision. This coincides with the results of many studies (e.g., [19]).

Table 4. Preferred Information Contents

Answer Options	1	2	3	4	5	6	7	Ranking Average
Occurrence and location of an incident	1	0	3	5	8	3	1	4.52
Occurrence and location of an incident + Expected delay (travel time) + Detour strategy	16	3	0	0	1	0	0	1.35
Expected delay (travel time)	1	3	1	2	2	7	5	5
Detour strategy	0	0	1	3	1	6	10	6
Occurrence and location of an incident + Expected delay (travel time)	1	6	9	3	2	0	0	2.95
Occurrence and location of an incident + Detour strategy	2	8	4	1	1	4	1	3.33
Expected delay (travel time) + Detour strategy	0	1	3	7	6	1	3	4.57

The last question asked about the possible reasons why users might stop using such a system. The results are shown in Table 5. The top three issues of great concern are “Too much irrelevant information,” “Negative impact on battery life,” and “Negative impact on other applications.” The comments made by two participants who selected “Other” are both related to message delay (“Timeliness of the announcements” and “Make sure information is current to make a good driving decision”).

Table 5. Results of Survey Question 10 (Reasons for Opting Out)

Q16. Under what circumstances will you opt out?	
Answer Options	Response Count (Percent)
Too much irrelevant information	7 (33.3 %)
Frequent information is distracting	1 (4.8 %)
Low sound quality (noisy sound)	0 (0.0 %)
Negative impact on the battery life	6 (28.6 %)
Negative impact on other applications running on the phone	5 (23.8 %)
Other	2 (9.5 %)

Summary

This chapter proposed the concept of the VDMS as the next-generation tool for DOTs to deliver en route traveler information. We also evaluated the smartphone application prototype system with a user survey. Several insights were offered in this process.

VDMS potentially fixes many of the flaws of DMS and other current en route traveler information systems. Auditory messages can deliver more-detailed information and reduce driver distraction. Scalable, location-based information can deliver more-relevant information to a wider area at minimal cost.

A user experience survey revealed a relatively positive attitude among subjects toward VDMS in terms of both usefulness and satisfaction. The survey also indicated that drivers feel VDMS is a safer way to receive information, and drivers feel more comfortable with VDMS compared with DMS.

Many research needs were also identified in this study, particularly the need for more-detailed market research based on user experience. Also, a more complex human factors study is necessary to resolve issues like how to deliver auditory messages, whether they are effective compared with DMS in terms of message comprehension, and what concerns regarding driver distraction need to be considered.

Chapter 2: Human Factors: Effectiveness of In-Vehicle Auditory Messages

On the basis of the preliminary results from the previous section, VDMS is a reasonable way to deliver traveler information that both meets with user acceptance and agrees with users' stated preferences. In order to provide a solid foundation for state DOTs and TMCs for future deployment, a well-designed human factors study was needed to investigate key aspects of how drivers perform when they receive messages: message comprehension, driver distraction, and the subjective level of difficulty that drivers feel.

Introduction

DMSs are the most widely used method to deliver public en route traveler information by public agencies. As discussed in earlier sections, DMSs are subject to many constraints that limit their effectiveness. The proposed VDMS is advantageous since it provides scalability for disseminating real-time traffic information to a large number of potential locations without the infrastructure costs of installing regular DMSs. More importantly, it can potentially provide more-detailed information, including basic messages and more-advanced routing advisories under emergencies (e.g., alternative routes). This section investigates whether VDMS can deliver information at least as well as current DMSs, which will help to determine if it is feasible for DOTs to deliver real-time traffic information using VDMS-equipped in-vehicle devices in the future, especially when CV systems are in place.

Although many studies have investigated human factors issues related to message design and display for in-vehicle route guidance systems, this paper differs from them in several aspects. The VDMS is proposed for use by DOTs to disseminate public traffic information, similar to current DMS messages, instead of providing visual/auditory, turn-by-turn information. The comprehension and distraction factors for a driver receiving VDMS navigation information differ greatly from that of a common DMS-type message. Also, to provide public agencies references for future development, we used the DMS, which is widely accepted, as the baseline and compared it with VDMS under the same experimental setup.

Objective and Scope

A human factors study using a driving simulator was performed in order to assess whether there were significant differences between traffic messages presented on a simulated DMS and VDMS. The specific objectives of this paper are to determine the ability of VDMS to reduce driver distraction compared with DMSs, to determine the comprehension of VDMS messages relative to DMS messages, and to determine the subjective difficulty level drivers feel when receiving messages from VDMS compared with DMS.

Methodology

A driving-simulator-based human factors study was conducted to assess driver performance and preferences between the proposed VDMS system and a simulated DMS. While real-world tests offer physical, perceptual, and behavioral fidelity, they are limited in terms of experimental controllability, reproducibility, and standardization. Meanwhile, driving simulators provide flexibility in experimental design and control, help to maintain consistency, and reduce confounding factors. Driving simulators can also provide richer driver performance data than can typically be obtained in field tests.

Driving Simulator Environment

The experiment was conducted using the Driver Guidance System (DGS; https://www.generalsimulation.com) at the University of Virginia. DGS is composed of simulation terminals and a data center with analysis tools to assess driving ability. The DGS collects performance data using a variety of driving scenarios and transmits the data to the data center for analysis, as shown in Figure 9. In Figure 10, the simulator terminal has a field of view subtended by approximately 200 degrees and an angular distortion error target of less than 1.5 degrees. The data are captured at a rate of 60 times per second (60 Hz). All control manipulations, positions, and orientations of vehicles are recorded. Figure 11 shows the real experimental setup and equipment. The messages, shown in a yellow pixelated font in a dark grey box, are projected to the screen using another projector. The messages appears clearer in reality than in the picture, and all participants reported that they could easily see the messages without extra effort.

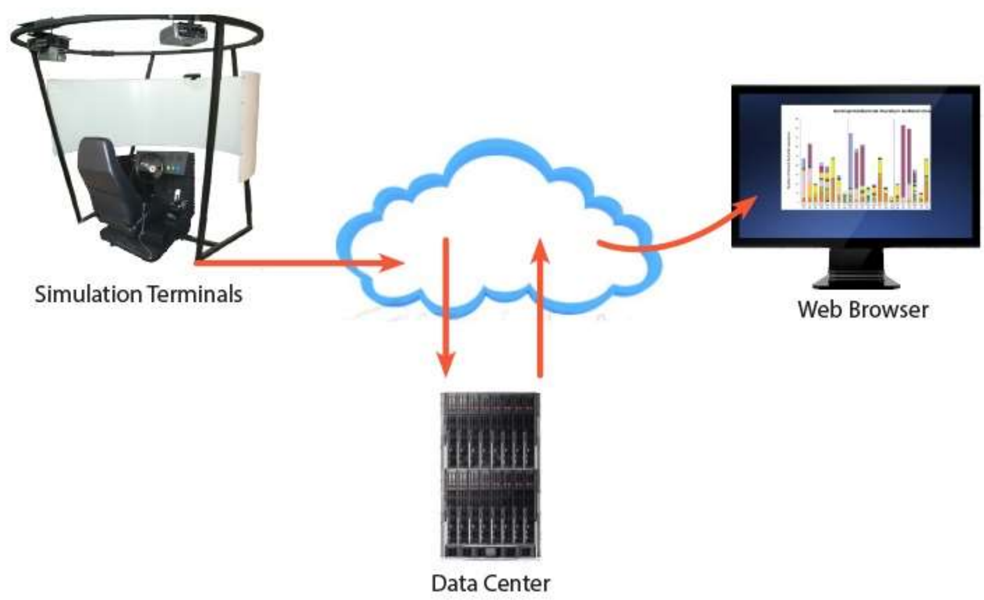

Figure 9. DGS components and data flow.

Figure 10. Driving simulator (car-following scenario).

Figure 11. Experimental setup and equipment (note simulated DMS in middle of screen).

Test Factors and Experimental Design

Message comprehension and driver distraction are the two most important measures of effectiveness when evaluating traveler information systems. Also, it is desirable that drivers subjectively feel comfortable with the traveler information being provided. In order to investigate these measures, an experimental design was created to test four factors that could influence driver comprehension and performance:

- Information mode (“Mode,” 2 levels)
    - DMS (text, level = 1)
    - VDMS (audio, level = 2)
- Information amount (“Amount,” 2 levels)
    - Low information load (3 units of information, level = 1)
    - High information load (6 units of information, two phases for DMS display, level = 2)
- Driving condition (“Driving,” 2 levels)
    - Simple driving scenario (level = 1)
    - Complex driving scenario (level = 2)
- Participant age (“Age,” 2 levels)
    - Young (18–60 years old, level = 1)
    - Old (> 60 years old, level = 2)

The DMS messages shown in Figure 11 were displayed in the center of the driving simulator screen for all scenarios using a separate projector connected to a laptop computer. Yellow characters in pixelated font were used to display experimental DMS messages to mimic real-world signs. Auditory messages were also delivered using the laptop computer and a separate speaker, placed next to the driving simulator. Also, the simulator generated engine noise based on the speed of the vehicle.

The definition of information units used in this study is consistent with the tenets advanced by Dudek and Huchingson for DMS messages in the *Manual on Real-Time Motorist Information Displays* [16]. The term refers to information that can be used to answer a simple question, such as “What is the traffic problem?”, “Where is the traffic problem located?”, and “What was told about the lanes?”. Also, the DMS and VDMS in this example used the same messages to avoid confounding factors.

The system used two pre-programmed scenarios to represent simple and complex driving environments. The first was a car-following scenario typical of a simple daily driving task. The participants were instructed to follow a lead vehicle at a constant speed and brake when the lead vehicle’s brake light was activated. The timing and number of braking activations of the lead car were random for each scenario and depended on the participants’ driving behavior. (If the driver never started driving, the lead vehicle waited for the following car and braking scenarios never occurred). The distance between two vehicles remained the same for all brake activations during different scenarios.

The simulation adjusted itself if drivers braked slowly or quickly or even failed to brake at any moment during the simulation. The brake light of the lead vehicle was only activated when a message had started to be broadcast or displayed. These settings made it difficult for participants to anticipate when the brake lights would be activated. Also, both short and long brake activations were randomly presented. It was unlikely that participants would opt to take no action (i.e., not respond) since they could not predict whether the lead car braking action would be only a momentary occurrence or a long brake. For long brake activations, participants had to brake to a stop to avoid crashing into the lead car.

The second scenario involved car-following while simultaneously avoiding potholes that were randomly shown on the road. Potholes, which were added to the brake light activations, were used to represent more-complex driving conditions. Potholes were shown on the ground, one after another, as three-dimensional objects; riding over them would cause obvious shaking and sound in the simulator. Drivers were told to avoid all potholes. Note that the locations of potholes were different in each scenario, depending on participants' driver behavior and scenario setup. For example, if a driver could not drive in the center of a specified lane, the potholes would never show up, and experimental data for the corresponding complex scenarios would not be used. The data was only considered valid when a driver could driver in the center of the lane and potholes showed up as designed.

A four-way mixed design (or partially repeated measure design; [41]) was used in this study. The repeated measure design was used for two reasons. First, there may be a great deal of variation between participants, such as self-reported message difficulty level, which may depend highly on each subject's characteristics. Then, error variance estimates from standard ANalysis Of VAriables (ANOVAs) are large. Repeated measures of each participant provide a way of accounting for this variance, thus reducing the error variance.

Mixed design was selected because, while Information Mode, Information Amount, and Driving Condition were within-subject independent variables, Participant Age was a between-subject independent variable. There were two levels for each factor, so the total number of different scenarios was $2 \times 2 \times 2 = 8$. Also, two replications were conducted for each scenario for each participant, which meant that each participant went through $8 \times 2 = 16$ scenarios.

The simulated driving environments of the 16 scenarios were very similar to each other, with only minor differences in surrounding environment, existence of potholes, timing of brake light activations, and timing of message. This was done to avoid introducing other confounding factors. In order to avoid practice and fatigue effects, the order of each scenario was randomly generated for each of the participants. This randomization also served to mitigate fatigue effects that could occur for scenarios tested at the end of the session. Details of the 16 scenarios and experimental messages are shown in Appendix B.

Participants

All participants were required to have a valid driver's license and drive at least 1,000 miles per year on freeways. Since this study needed to examine the effect of age as a factor, both younger and older participants were recruited.

The statistical software G Power 3 [42] was used to calculate sample size. The software permits a priori power analysis (i.e., calculate sample size for given effect size, alpha, power, and design). Based on Cohen's recommendation [43-45], several assumptions of required parameters were made: median effect size (0.25), power value (0.8), correlation among repeated measures (0.5), and non-sphericity correction (1, for within-between factor interaction). The required sample sizes for between factors, within factors, and within-between interactions were calculated separately; the values of the above assumptions with median effect size were 22, 10, and 12. For example, when we assumed a smaller effect size of 0.20, the required sample size became 34. To account for the possibility of small effect size and also considering time and resources available, 46 participants were recruited. Four of them were not able to finish the experiment due to simulation sickness. Therefore, data analysis was conducted with the remaining 42 participants (27 young and 15 old, 20 male and 22 female), with age ranges from 19 to 73. The mean age for the younger driver group was 25.6 (SD=5.58) and the mean age of the older driver group was 65.3 (SD = 6.58). All of the participants met the basic eligibility requirements and none of the participants reported having any vision and hearing deficiencies.

Experimental Procedure

Each participant was tested using the same procedures. First, written instructions were read to each participant. They were instructed on the goals of the study, told about the driving simulator, and told about compensation procedures. Next, each participant was given 10 to 15 minutes to get familiar with the driving environment before the test started. This was done to reduce testing bias related to lack of driver familiarity with the simulator. The practice driving scenarios were quite similar to the formal test environment. This was done to reduce the impact of unfamiliarity with the simulator that could be manifested during the initial runs for each subject.

The testing phase then began. Each participant was tested using the 16 scenarios in randomized order. Each scenario lasted about 2 to 3 minutes. The entire set of 16 scenarios was completed in approximately 40 to 50 minutes. In each scenario, participants drove one of the two driving conditions (simple or complex) and received one type of traffic message (DMS/VDMS and short/long message). These messages were very similar to current DMS traffic messages used by DOTs, such as "Crash Ahead, Interstate 64 Eastbound Exit 112, Right lane closed." Sometimes the message might also contain travel time information, such as "To US 29, 20 minutes via I-64."

Note that, since the experiment was conducted in Charlottesville, Virginia, every message used in this experiment used local routes in the messages that were tested. Before the experiment was conducted, participants were given a map and asked to imagine that they were driving at a location before a diversion point. After they saw or heard a message, the experimenter would wait for another 20 seconds before asking participants open-ended questions for each information unit, such as “What is the traffic problem?” and “What is the travel time to US 20 via I-64?”. Each participant also needed to self-report the difficulty level of processing the messages in each scenario under the corresponding driving condition on a five-point Likert scale (1 – Not difficult, 2 – A little difficult, 3 – Medium difficulty, 4 – Relatively difficult, and 5 – Very difficult).

Evaluation Metrics and Data Analysis

Several evaluation metrics were used to evaluate driver performance in terms of message comprehension, driver distraction, and preference. Message comprehension was measured based on participants’ answers to open-ended questions asked by the experimenter. The proportion of questions correctly answered corresponding to message information units was the performance measure. For example, correctly answering three questions out of five would be assigned a comprehension value of 3/5 = 0.6.

Time-to-brake was used as a surrogate measure for level of driver distraction. This measure was computed by the simulator as the time that elapsed between when the lead vehicle’s brake lights activated and when the driver began to step on the brake. This measure was used to assess whether there may be any adverse safety impacts for different factor combinations.

Finally, self-reported difficulty in processing each message under each specific driving condition was also collected. This difficulty level was reported using a five-point Likert scale (1 – Not difficult, 3 – Medium difficulty, 5 – Very difficult). This was a comprehensive measure that could include factors like distraction, preference, and ability of each participant to process visual/audio messages.

In summary, the evaluation metrics used in this study were as follows:

- Message understanding based on the proportion of the open-ended questions that were correctly answered (interval);
- Driver distraction based on time-to-brake (interval);
- Subjective message difficulty level rating based on the five-point Likert scale (ordinal).

To examine the effects of the experimental conditions, mixed ANOVAs were applied. As described above, a value between 0 and 1 was assigned based on the percentage of messages that were comprehended, and, in this way, the general framework of mixed ANOVA was used to analyze this metric as well. Gene Glass et al. did a well-known Monte Carlo study of ANOVA. It showed that the *F*-test was incredibly robust to violations of the interval data assumption (as well as moderate skewing), and it could be used to do statistical tests at the scale level of the data (collected using a 5- to 7-point Likert response format) with no resulting bias [46]. Many other studies also confirmed the conclusion and applied this result to their application [47]. Therefore, ANOVA was also applied in this study for analysis of Likert-scale data.

A mixed four-way ANOVA using the Generalized Linear Model (GLM) function in the Statistical Package for Social Sciences (SPSS), was carried out to analyze the experimental data. Repeated measures ANOVA carried the standard set of assumptions associated with an ordinary analysis of variance, extended to the matrix case: multivariate normality, homogeneity of covariance matrices, and independence. Repeated measures ANOVA was robust to violations of the first two assumptions. Violations of independence produced a non-normal distribution of the residuals, which resulted in invalid F ratios. This study selected participants randomly and the independence assumption should be fulfilled [41].

Results

Message Comprehension

GLM was run using message comprehension data (proportion of questions that were correctly answered) collected by the experimenter with open-ended questions. This measure reflected the percentage of information that participants correctly processed and retained. The main effects, two-factor interactions, and significant three-factor interaction results have been listed in Table 6. Note that other three-factor interaction and four- factor interaction effects were not significant and thus not listed in the table for concision. Multivariate test statistics, such as Pillai's Trace and Wilks' Lambda, have usually been used due to their robustness; we used the former in this paper [43].

Table 6. Mixed ANOVA Test Results for Message Comprehension

	F	**df**	**Sig.**	**Partial Eta Squared**
Within-subjects effects				
Mode	40.386	1	.000	.502
Amount	102.689	1	.000	.720
Driving	10.079	1	.003	.201
Mode*Amount	2.222	1	.144	.053
Mode*Driving	12.797	1	.001	.242
Amount*Driving	2.740	1	.106	.064
Mode*Amount*Driving	22.123	1	.000	.356
Between-subjects effects				
Age	8.102	1	.007	.168
Within-between interaction effects				
Mode*Age	1.135	1	.293	.028
Amount*Age	1.141	1	.292	.028
Driving*Age	.899	1	.349	.022

Table 7. Post Hoc Comparisons of Factors Mode, Amount, and Driving for Message Comprehension

Amount	Driving	(I) Mode	(J) Mode	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
							Lower Bound	Upper Bound
1	1	1	2	.034	.027	.218	-.021	.089
	2	1	2	-.208	.035	.000	-.280	-.137
2	1	1	2	-.173	.036	.000	-.246	-.100
	2	1	2	-.102	.028	.001	-.158	-.046
Mode	**Driving**	**(I) Amount**	**(J) Amount**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
							Lower Bound	**Upper Bound**
1	1	1	2	.291	.041	.000	.208	.374
	2	1	2	.185	.037	.000	.111	.258
2	1	1	2	.084	.036	.024	.012	.156
	2	1	2	.291	.026	.000	.239	.343
Mode	**Amount**	**(I) Driving**	**(J) Driving**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
							Lower Bound	**Upper Bound**
1	1	1	2	.153	.041	.001	.071	.236
	2	1	2	.047	.029	.110	-.011	.106
2	1	1	2	-.089	.030	.005	-.149	-.029
	2	1	2	.119	.024	.000	.071	.166

*Mode 1: DMS; Mode 2: VDMS; Amount 1: three units of information; Amount 2: six units of information; Driving 1: Low complexity; Driving 2: High complexity.

The results revealed significant main effects for Mode, Information Amount, and Driving Complexity. Within-subject interactions between Mode and Driving, as well as between Mode, Driving, and Amount were also significant. Other interaction effects between within-subject factors and within-between interaction effects were not statistically significant. Note that the Partial Eta Squared in Table 6 (and in other similar tables in this paper) was the statistic used to indicate the calculated effect size (0.01 = small, 0.06 = medium, 0.13 = large, according to Cohen [43]. Clearly, all the significant main or interaction effects had a large effect size and should be fully considered in the information system design.

Due to the significant interaction effects, we conducted further pairwise comparisons as shown in Table 7. In the first block of Table 7, the effect of Mode is not significant only when driving complexity and message length are both low, but is significant for all other combinations. This means that, while DMS and VDMS perform similarly under less demanding conditions, the comprehension of VDMS messages is significantly better than DMS under complex conditions or for longer messages, regardless of driving complexity. On average, the comprehension rate of VDMS is 16% higher than DMS under these conditions.

The second block of Table 7 reveals the effect of the amount of information. For DMSs, longer messages reduce comprehension level, which is expected, since it is more difficult for drivers to read and process longer messages within a specific time frame. However, this is true for VDMS only under complex driving conditions; there is no significant difference between the comprehension of short and long messages under simple driving conditions. This means that, under simple driving conditions, it is more viable to provide more information with VDMS since it will not significantly reduce message comprehension.

The effect of driving complexity is shown in the third block of Table 7. Generally, complex driving conditions cause lower comprehension levels of messages than simple driving conditions. The one exception is DMS, which has higher information content. It is possible that the effect of more information is larger than the effect of more complex driving conditions, which is partially demonstrated by the value of Partial Eta Squared in Table 6 (Amount = 0.702, Driving = 0.201). Although both of them are larger than 0.14 (and these are of large effect size), the effect size of amount of information is more than three times that of driving complexity.

The between-subject variable, Age, is also significant at a 95% level. There are no significant interaction effects between between-subject and within-subject factors. This indicates that older drivers cannot process and retain as much information as young drivers in all conditions under the experimental settings. For this reason, both DMS and VDMS should be designed in a way that is still acceptable for older drivers. In particular, non-significant interaction between Mode and Age indicates that the effect of Mode is not dependent on Age. This means that all the main effects obtained in this section apply to both young and old drivers. For example, VDMS is significantly better than DMS for both young and old drivers under relatively complicated conditions, in terms of either information load or driving complexity.

Driver Distraction

Driver distraction was measured by the time-to-brake, which provides a surrogate measure for the safety effects of each factor. The main effects, two-factor interactions, and significant three-factor interaction results using Wilks' Lambda, can be seen in Table 8. Note that other three-factor interaction and four-factor interaction effects were not significant and, thus, were not listed in the table for the sake of conciseness.

Table 8. Mixed ANOVA Test Results for Distraction Using Time-to-brake Data

	F	df	Sig.	Partial Eta Squared
Within-subjects effects				
Mode	204.537	1	.000	.836
Amount	.739	1	.395	.018
Driving	17.710	1	.000	.307
Mode*Amount	.037	1	.849	.001
Mode*Driving	8.941	1	.005	.183
Amount*Driving	.763	1	.388	.019
Mode*Amount*Driving	.021	1	.886	.001
Between-subjects effects				
Age	.893	1	.350	.022
Within-between interaction effects				
Mode*Age	0.967	1	.331	.024
Amount*Age	.041	1	.840	.001
Driving*Age	1.092	1	.302	.027

Table 9. Post Hoc Comparisons of Factors Mode and Driving for Distraction

Driving	Mode (I)	Mode (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
1	1	2	.308*	.036	.000	.236	.380
2	1	2	.475*	.042	.000	.390	.560
Mode	**Driving (I)**	**Driving (J)**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference[a]**	
1	1	2	-.194*	.050	.000	-.295	-.094
2	1	2	-.027	.022	.218	-.071	.017

*Mode 1: DMS; Mode 2: VDMS; Driving 1: Low complexity; Driving 2: High complexity.

The results reveal significant effects for two main within-subject factors: Mode and Driving, and interaction effects between Mode and Driving. The information amount factor is not significant. This may be a case of the driver prioritizing safe control of the vehicle over traveler information.

There are significant interaction effects between Mode and Driving, so caution should be used when interpreting the main effects of those factors. Post hoc pairwise comparisons for the effects of Mode*Driving are shown in Table 9. Under both simple and complex driving conditions, the effect of Mode is statistically significant. This confirms the significant main effect of Mode, and shows that the time-to-brake for VDMS is, on average, 0.39 seconds shorter than for DMS. This implies that VDMS has less of an effect, in terms of distraction level, under both simple and complex driving conditions than DMS. However, the effect of driving complexity is only significant for the DMS mode and not significant for VDMS (p = 0.218). This indicates that the complex driving condition significantly increases the DMS message distraction level, while distraction level was not significantly increased by more complex driving conditions for VDMS messages. Since traffic messages are often provided during complex traffic conditions created by congestion or incidents, this result reveals another potential benefit of VDMS over DMS.

The main effect of the between-subject variable Age and interaction effects between within-subject effects and Age are not statistically significant, as shown in Table 8. We can conclude that there is no significant difference between young and old drivers in their time-to-brake as they are processing traffic messages.

In addition to time-to-brake, the number of times when participants struck the lead vehicle was also recorded. In total, among the 672 discrete scenarios (16 for each of 42 participants), there were 11 crashes during DMS scenarios and 3 crashes for VDMS scenarios. Though the data set is not large enough to test for statistical significance, the large difference in crash frequency may be an indicator of the potential benefit of VDMS in reducing distraction.

Perceived Difficulty

A mixed ANOVA was run using the participants' Likert difficulty rating data for each scenario. This measure examines the perceived difficulty for the driver to process and retain messages under different driving conditions. This is a subjective measure, but drivers' perceptions may greatly affect the perceived effectiveness of a traveler information system. The main effects, two-factor interaction, and significant three-factor interaction results based on difficulty level data, are shown in Table 10 and Table 11. Note that other three-factor interaction and four-factor interaction effects are not significant and thus not listed in the table for concision. Again Wilks' Lambda is used here to test for significance.

Table 10. Mixed ANOVA Test Results for Distraction Using Likert Difficulty Rating

	F	**df**	**Sig.**	**Partial Eta Squared**
Within-subjects effects				
Mode	41.642	1	.000	.510
Amount	163.020	1	.000	.803
Driving	12.164	1	.001	.233
Mode*Amount	3.906	1	.055	.089
Mode*Driving	12.727	1	.001	.241
Amount*Driving	6.676	1	.014	.143
Mode*Amount*Driving	28.408	1	.000	.415
Between-subjects effects				
Age	17.509	1	.000	.304
Within-between interaction effects				
Mode*Age	2.030	1	.162	.048
Amount*Age	2.159	1	.150	.051
Driving*Age	2.175	1	.148	.052

Table 11. Pairwise Comparison for Interactions Effect Between Three Within-subject Factors for Perceived Difficulty

Amount	Driving	(I) Mode	(J) Mode	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
							Lower Bound	Upper Bound
1	1	1	2	.128	.142	.372	-.158	.414
	2	1	2	1.137	.109	.000	.916	1.358
2	1	1	2	.633	.126	.000	.378	.889
	2	1	2	.241	.119	.049	.001	.481
Mode	**Driving**	**(I) Amount**	**(J) Amount**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
							Lower Bound	**Upper Bound**
1	1	1	2	-1.419	.137	.000	-1.695	-1.142
	2	1	2	-.985	.121	.000	-1.230	-.741
2	1	1	2	-.913	.163	.000	-1.242	-.584
	2	1	2	-1.881	.139	.000	-2.163	-1.600
Mode	**Amount**	**(I) Driving**	**(J) Driving**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
							Lower Bound	**Upper Bound**
1	1	1	2	-.602	.141	.000	-.887	-.317
	2	1	2	-.169	.113	.142	-.396	.059
2	1	1	2	.407	.105	.000	.195	.620
	2	1	2	-.561	.097	.000	-.758	-.365

*Mode 1: DMS; Mode 2: VDMS; Amount 1: three units of information; Amount 2: four units of information; Driving 1: Low complexity; Driving 2: High complexity.

The results reveal significant effects for all three main within-subject factors (Mode, Amount, and Driving), and all two-way and three-way interaction effects, as shown in Table 10. Subjects were sensitive to the changes in all three factors, but the effect of changes in one factor was dependent on the changes of other factors. Thus, we need to further examine the post hoc comparisons between the factors.

The first block of Table 11 shows that the effect of Mode on perceived difficulty level is significant under all combinations of Amount and Driving except under the most simple conditions (low information context and driving complexity). This implies that VDMS can significantly reduce the perceived difficulty level for drivers except under simplest conditions, where drivers perceive the two modes as having a similar difficulty level. The effect of Amount, shown in the second block of the table, indicates a significant effect of Amount under all conditions. This was expected, since people may be more subjectively sensitive to difficulty caused by increased amount of information. Driving complexity results are similar to those seen for the comprehension level, and are shown in the third block of Table 11. Complex driving conditions are generally perceived as making message processing more difficult for drivers than simple driving conditions. The exception is the DMS, which has a high information amount, possibly because the effect of more information is larger than the effect of more complex driving conditions. This is partially demonstrated by the value of Partial Eta Squared in Table 10 (Amount = 0.803, Driving = 0.233).

The between-subject variable, Age, is significant, while the interaction effects between within-subject factors and within-between interaction effects are not statistically significant. It can be concluded that there are significant differences in the perceived difficulty level of processing and retaining messages between young and old drivers. However, trends in the effect of Mode, Amount, and Driving are similar in both younger and older drivers.

Summary

This study conducted a driving simulator-based experiment to examine the effectiveness of VDMS. Table 12 summarizes key attributes of VDMS compared with DMS.

Table 12. Comparison of DMS vs. VDMS

Aspect	Comparison between DMS and VDMS
Comprehension	• For short messages and simple driving conditions, there was no significant difference between DMS and VDMS. VDMS has a significantly higher comprehension rate when information loads are high or when driving conditions became more complex. • VDMS can be used to provide longer messages than DMS under simple driving conditions since comprehension is not negatively impacted by message length for VDMS.
Distraction	• Time-to-brake with VDMS was on average 0.39 seconds shorter than DMS under both simple and complex driving conditions. • Complex driving conditions significantly increased time-to-brake with the DMS, while time-to-brake did not significantly increase with driving complexity for VDMS. • The two points above apply to both young and old drivers.
Difficulty	• VDMS had a significantly lower perceived difficulty level for drivers than DMS except under the simplest conditions (low information load and simple driving condition). • The point above applies to both young and old drivers.

Based on this evaluation, VDMS provides traffic information that is comparable, and possibly better than, that currently offered by DMSs. It means that VDMS can increase drivers' message comprehension level and can potentially deliver more information. Also, VDMS showed positive results in reducing time-to-brake when compared with DMS messages.

This chapter investigated the effectiveness of using in-vehicle auditory systems (VDMS) to deliver public traffic messages compared with DMS. The findings revealed that VDMS is generally a better way to deliver traffic messages containing different amounts of information under different driving conditions for both young and old participants. VDMS can generally help increase message comprehension, reduce distraction, and make the same messages easier to process and retain than can DMS. Also, drivers prefer using VDMS rather than DMS to receive information. The conclusion of this paper reveals the advantages of VDMS and can serve as evidence for public agencies to deploy VDMS systems in the future.

Since this was one of the first studies to evaluate the feasibility and effectiveness of a system similar to VDMS, there are still some limitations and unanswered questions to be explored in the future. First, although driving simulators are commonly used in traffic research (due to their practicality and high level of experimental control), replications of the study in real-life driving settings, such as via on-road assessments, are needed in order to ensure the generalizability of the findings. Second, the current experimental design is simplified in some aspects (e.g., two levels for each factor) and ignores some other factors (e.g., gender, education level).

Further studies are needed to investigate more factors with higher levels of information. Third, the VDMS auditory messages in this paper are only audio versions of similar visual DMS messages. In practice, there are other strategies to make VDMS messages more effective, such as repeating key and difficult information twice; this cannot be achieved using DMS. The effectiveness of these improvements should be further evaluated to improve the VDMS design. Also, displaying more complex messages (e.g., maps/visual texts on an in-vehicle device screen along with detailed auditory messages) is not considered in this paper. Further studies can be conducted to determine whether it is appropriate for DOTs to provide detailed information while limiting the distractions to reasonable level.

Next, there are other human factors issues for VDMS messages (such as characteristics of the voice and structure of the auditory messages) that need to be addressed in future research. Another possible future item would be to examine levels of ambient noise and their effect on driver performance with VDMS. Last, this study used scenarios on a local network that subjects would be familiar with. It is important to investigate whether results hold for non-local drivers traveling an unfamiliar network.

Contributions and Future Research

This research investigated the new concept of VDMS to support next-generation Public Traveler Information. The concept leverages communication between vehicles and infrastructure. The development of one of the first smartphone-based CV traveler information applications, VDMS, is the subject of this study. This research is also among the first studies to evaluate the human factors issues regarding the effectiveness of VDMS concepts in delivering public messages. Several areas for future research are identified that represent logical extensions of the ideas presented in this study.

Research Contributions

This study provided several contributions to the state of knowledge in advanced traveler information systems. Specific contributions include the following:

Innovative VDMS Concepts

This research is the first work in the literature proposing and comprehensively evaluating the concept of VDMS. The concept is different from most of the current public and private information systems because it possesses the following attributes:

- **Scalable deployment:** By using cyber infrastructure and personal devices, the information can be deployed anywhere if needed, with only marginal added cost.
- **Personalization:** The information could target each individual traveler, based on their individual needs and attributes, such as current location, habitual routes, and value of time.
- **Auditory messages:** This allows more flexibility in delivering messages, based on the desired message type, information units, contents, language, and other personal preferences.
- **Better comprehension:** As proven by this study, driver comprehension is usually better for VDMS than for DMSs with different messages and driving conditions.
- **Low distraction:** As proven by this study, driver distraction of VDMS is usually lower than DMSs with different messages and driving conditions.
- **Dynamic traffic management strategies:** With the flexibility of information delivery, more-sophisticated information strategies could be applied to better dynamically manage real-time traffic, particularly under special conditions.

Prototype and Evaluation

This research represents one of the first efforts to develop a CV traveler information app that will demonstrate the proposed VDMS concept. The attitudes of users toward this transportation telematic are surveyed. This is of particular importance since only the transportation telematics subjectively accepted by the travelers can become widely used and effective as designed.

The focus group user survey reveals a positive attitude among subjects toward VDMS in terms of both usefulness and satisfaction, with an average rating of −0.90 and −0.81 on a −2 to 2 (Totally agree to Total disagree) five-point Likert scale. The survey also indicates that potentially most drivers (80.95%) perceive that VDMS is a safer way to receive information; most drivers (66.67%) feel more comfortable receiving information from VDMS compared with DMS. The results indicate great user acceptability and the potential for such systems to be deployed by public agencies in the future.

Effectiveness of Information Delivery by VDMS

This research is one of the first efforts to investigate whether VDMS delivers information at least as well as current DMSs. It explores whether it is feasible for DOTs to transfer real-time traffic information dissemination to in-vehicle devices in the future using VDMS, looking at the subject from the perspective of message delivery, given its advantages in costs and scalability. Note that this study is different from many previous studies investigating human factors issues for the message and display design of in-vehicle route guidance systems. This study makes unique contributions due to the unique attributes of VDMS concepts. The messages we are considering in this study are public traffic information similar to current DMS messages, instead of visual/auditory turn-by-turn information along with digital maps in a route-guidance system. The comprehension and distraction potential of information like turning instructions can be potentially different from that of a common public message, such as the locations of incidents and possible delays, and thus warrant independent study.

Analysis results revealed that VDMS generally performs better than DMS across different amounts of information and under different driving conditions, regardless of driver age.

- **Message Comprehension:** There are no significant differences for short messages and simple driving conditions. However, VDMS is significantly better when information loads are high or when driving conditions became more complex. Also, VDMS can be used to provide longer messages than DMS under simple driving conditions since comprehension is not negatively impacted by message length for VDMS.
- **Driver distraction:** Time-to-brake with VDMS was on average 0.39 seconds shorter than DMS under both simple and complex driving conditions. Complex driving conditions significantly increased time-to-brake for DMS, while time-to-brake did not significantly increase with driving complexity for VDMS.

- **Subjective difficulty level:** VDMS had a significantly lower perceived difficulty level for drivers than DMS except under the simplest conditions (low information load and simple driving condition).

Based on these results, it is recommended that transportation agencies give careful consideration to VDMS as a future strategy for delivering public traffic information in a CV environment.

Future Research

Since this is the first study to evaluate the feasibility and effectiveness of VDMS, there are still some limitations and unanswered questions to be explored in the future. First, although driving simulators are commonly used in traffic research (due to their practicality and high level of experimental control), replications of the study in real-life driving settings, such as via on-road assessments, are needed in order to ensure the generalizability of the findings. Second, the current experimental design is simplified in some aspects (e.g., two levels for each factor), and ignores some other factors (e.g., gender, education level).

Further studies are needed to investigate more factors with more levels, such as higher levels of information. Third, the VDMS auditory messages used in this study were only audio versions of similar visual DMS messages, while in practice there are other strategies to make VDMS messages more effective, such as repeating key and difficult information twice, which is not achievable in DMS. The effectiveness of these improvements should be further evaluated as well to improve the VDMS design. Also, displaying more complex messages (e.g., maps/visual texts on an in-vehicle device screen along with detailed auditory messages) are not considered in this paper. Further studies can be conducted whether it is appropriate for DOTs to provide detailed information while limiting the distractions to reasonable level.

Next, there are other human factors issues for VDMS messages, such as characteristics of the voice and structure of the auditory messages, that need to be addressed in future research. Another possible future area of research would be to examine levels of ambient noise and their effect on driver performance with VDMS. Last, this study used scenarios on a local network that subjects would be familiar with. It is important to investigate whether results hold for non-local drivers traveling an unfamiliar network.

Appendix A

User Experience Survey Questions

Introduction

This is a user experience survey on the usage of the virtual DMS smartphone application, VDMS, developed at the Center for Transportation Studies, the University of Virginia. You are asked to fill out the survey after using the smartphone application for several times. In this survey, questions will be asked questions about your attitude the smartphone application and preferences for some future features.

Part I Basic information

Gender ○ Male ○ Female

Age
○ <20 ○ 20-29 ○ 30-39 ○ 40-49 ○ 50-64 ○ ≥65

Education level
○ High school or less ○ Some college
○ College graduate ○ Post graduate

Part II Attitude Survey

This part of the questionnaire intends to capture your attitude toward the usefulness and satisfaction with the service delivered by the VDMS application. Please provide your answers to the questions below based on your experiences. The responses are going to be recorded using a five-point Likert scale (-2 to 2). Note the smartphone application refers to the app you have been using and the DMS refers to dynamic/variable message signs found along a roadway.

For After study:
What is your judgment about the VDMS system based on your experience with it in the past several weeks? Please indicate the answer based on the following eight items/attributes.

Your judgment toward the VDMS system are: (please tick a box on every line)							
		-2	-1	0	1	2	
1	Useful						Useless
2	Pleasant						Unpleasant
3	Good						Bad
4	Nice						Annoying
5	Effective						Superfluous
6	Likeable						Irritating
7	Assisting						Worthless
8	Desirable						Undesirable
9	Raising alertness						Sleep-inducing

Part III Experience Survey

In this part, you will need to answer some specific questions based on your experience of VDMS system. You will also be asked questions for future app system design and development based on your stated preference.

1. Was the information provided relevant? (1 means "Completely Disagree" and 5 means "Completely Agree")
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

2. Did you receive the information in time? (How was the timing?) (1 means "Really Bad" and 5 means "Really Good")
○ 1 ○ 2 ○3 ○ 4 ○5

3. Which message type do you prefer?
○ Smartphone audio message
○ Smartphone text message
○ DMS message on a roadway

4. Is the audio message sent to your phone safer to use compared with a roadside DMS text message?
○ Yes ○ No

5. Is the audio message sent to your phone more comfortable to use compared with a roadside DMS text message?
○ Yes ○ No

5. Do you attach more value to (better to comply with) the audio message sent to your phone compared to a roadside DMS text message?

○ Yes ○ No

6. What is the appropriate number of repetitions for each message? (How many times should the application read the same message to you?)
○ 1 ○ 2 ○ 3 ○ More than 3

7. In your opinion, can the smartphone application completely substitute the current physical DMS deployments?
○ Yes ○ No
If not, please state the reason: ____

8. Would you like to receive messages at locations other than current DMS locations?
○ Yes, other places on the highway where there is congestion or incidents
○ Yes, other places on the highway and arterials where there is congestion or incidents
○ No

9. Please rank the following six messages that you will be willing to receive during the travel.
____Occurrence and location of the incident
____Expected delay (travel time)
____Detour strategy
____Occurrence and location of the incident + Expected delay (travel time)
____Occurrence and location of the incident + the detour strategy
____Expected delay (travel time) + the detour strategy

10. Under what circumstances will you opt out? (Please indicate one option)
○ Too much irrelevant information
○ Frequent information is noisy/distracting
○ Negative impact on the battery life
○ Negative impact on other applications running on the phone
○ Other: ____

11. Do you have any additional comments or suggestions about the future features, or any functional improvement to the application?
____
Thank you!

Appendix B

Scenarios, Experimental Messages and Maps Used in the Human Factor Study

At the beginning of the experiment, the driver is told that he is driving along Interstate 64 Eastbound toward US 29. The alternative of I 64 for the driver is US 250, as shown in the following map In Figure B1. All the messages below apply to this driving location.

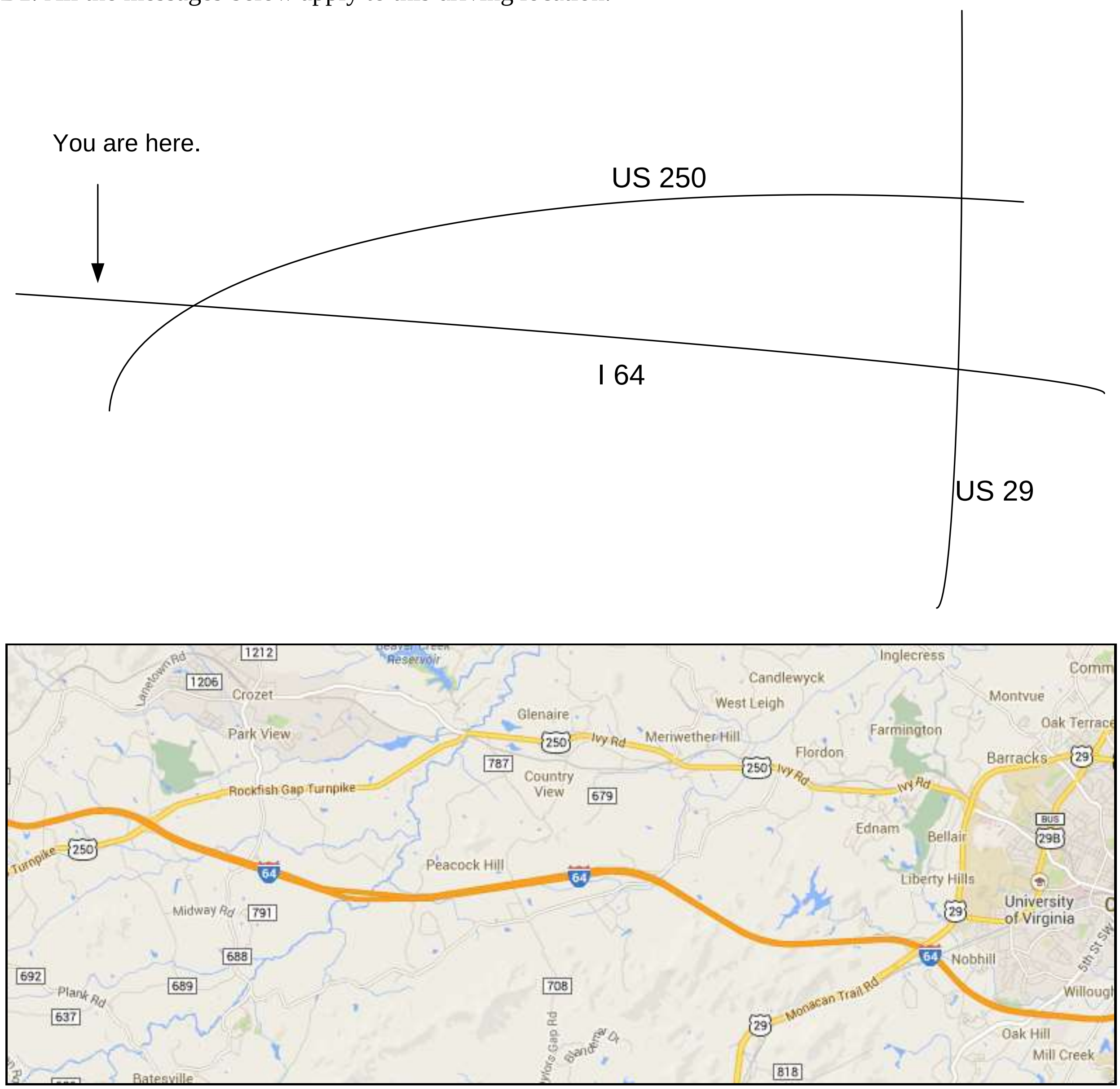

Figure B1 Maps shown to the users before the experimental design

The sixteen experimental scenarios and the numbering is shown in Table B1.
Table B1 16 Experimental scenarios

	Mode	Amount	Drive Condition
1	dms	Low	Low
2	vdms	Low	Low
3	dms	High	Low
4	dms	Low	High
5	vdms	High	Low
6	vdms	Low	High
7	dms	High	High
8	vdms	High	High
9	dms	Low	Low
10	vdms	Low	Low
11	dms	High	Low
12	dms	Low	High
13	vdms	High	Low
14	vdms	Low	High
15	dms	High	High
16	vdms	High	High

All the messages corresponding each of the 16 scenarios are shown below:

1.
ACCIDENT I-64 E
AT EXIT 110
LEFT LANE CLOSED

2.
New message: Roadwork at Interstate 64 Eastbound near exit 112. Right lane is closed.

3.

First Phase	Second Phase
ACCIDENT I-64 E AT EXIT 122 LEFT LANE CLOSED	TIME TO US 29 20 MIN VIA I-64 15 MIN VIA US-250

4.
EXPECT DELAY AHEAD
I-64 E TO EXIT 116
RIGHT LANE CLOSED

5.
New message: Rock slide at Interstate 64 eastbound, near Exit 112. Right lane is closed. Expect delays, 20 minute 10 miles. Use alternative US-250.

6.
New message: Crash at Interstate 64 Eastbound near mile marker 113. Right lane is closed.

7.

First Phase	Second Phase
ROCK SLIDE I-64 E MM 109 LEFT LANE CLOSED	DELAYS 25 MIN 10 MILES USE ALT US-250

8.
New Message: Major accident ahead at Interstate 64 east prior to mile marker 114, right lane is closed. Travel time to US 29 is 30 minutes via Interstate 64, and, as an alternative, 20 minutes via US 250.

9.
MOBILE ROADWORK
I-64 E EXIT 111-116
RIGHT LANE CLOSED

10.
New Message: Delay expected at Interstate 64 eastbound after Exit 115. 20 minutes for 10 miles.

11.

First Phase	Second Phase
CRASH I-64 E PRIOR TO EXIT 112 EXPECT DELAY	TIME TO US 29 25 MIN VIA I-64 17 MIN VIA US-250

12.
TO US 29 VIA I64
13 MILES
16 MINUTES

13.
New Message: Major accident ahead Interstate 64 East at Exit 117, right lane is closed. Heavy congestion, travel time to US 29 is 35 minutes for 10 miles. Use alternative US-250.

14.
New message: Major accident ahead, left lane is closed. Use alternative US-250.

15.

First Phase	Second Phase
MAJOR CRASH I-64 E	TIME TO US-29

MM 113 EXPECT DELAY	32 MIN VIA I-64 18 MIN VIA US-250

16.

New Message: Major accident at Interstate-64 East, 2 miles back up to exit 109. Use alternative US-250, 12 minutes for 11 miles to US 29.

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