ABSTRACT

Title: **IMPACT OF DYNAMIC MESSAGE SIGNS ON OCCURRENCE OF ROAD ACCIDENTS**

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Dynamic Message Signs (DMS) are key components of Advanced Traveler Information Systems to manage transportation networks, reduce congestion and improve safety through providing motorists with real-time information regarding downstream traffic conditions. While DMSs are intended to improve efficiency and safety of road networks, little has been done to study the effect of the signs on driver safety and their localized safety impacts. This thesis employs ground truth data as the basis to investigate the issue in State of Maryland in a four-year period (2007-2010). The results show no significant difference between the accident pattern in the proximity of DMSs and the onward adjacent segments. On-and-off study is also conducted on DMS operation status (on/off). The results converge with the previous analysis suggesting that there is no meaningful relationship between occurrence of accidents and presence of DMSs. Besides, statistical analysis on DMS characteristics and accidents in impact areas are performed.

IMPACT OF DYNAMIC MESSAGE SIGNS ON OCCURRENCE OF ROAD ACCIDENTS

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Thesis submitted to the Faculty of the Graduate School of the University of Maryland, College Park, in partial fulfillment of the requirements for the degree of
Master of Science
2012

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To Keivan and Jiwan

Acknowledgement

I am deeply grateful to my advisor, Professor Ali Haghani, for providing me the opportunity, motivation, and guidance all throughout my education. Without his instruction, assistance and encouragement this thesis would never have been completed. I also sincerely appreciate his kindness and genuine care to my family.

I would also like to thank all of the professors and instructors who contributed their time and knowledge to my education. Specifically, I acknowledge my gratitude to Dr. Ali Haghani and the other faculty members, Dr. Paul Schonfeld and Dr. Cinzia Cirillo for their willingness to serve on my committee and their constructive feedback and valuable guidance, as well as their efforts throughout my coursework.

My great thanks go to my colleagues within my research group, specifically Dr. Masoud Hamedi for helping and encouraging me throughout my research and providing great ideas for our shared research. I also thank him for his assistance in coding during the process of integrating the databases.

My most special thanks and appreciation goes to my dear husband, Dr. Keivan Ghoseiri. I owe my education to him. He has always motivated me and offered his sincere help and guidance throughout my studies including this research. I dedicate this thesis to him for one decade love and devotion and our joy of life, Jiwan.

Finally, I want to thank my beloved parents to whom I am indebted forever for their love and affection.

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Chapter 1: Introduction

1.1. Research Motivation and Objectives

Increasing traffic volumes over recent decades is the compelling motivation to manage transportation networks, increase capacity, enhance the communication capabilities of transportation systems, improve safety and reduce congestion. Physically increasing the capacity of roadways and arterials by adding lanes is not economically and environmentally justified most of the times and is generally seen as an ineffective solution in the long term. One of the most popular alternative strategies is to provide travelers with real time information regarding downstream traffic conditions using Advanced Traveler Information Systems (ATIS). Two of the main technologies employed in this effort are Highway Advisory Radio (HAR) and Dynamic Message Signs (DMS). DMSs are often regarded as the most visible form of ATIS since they are available equally to all road users. Some of the most popular types of messages displayed on DMS are weather conditions, travel time, construction information, speed limits, incident locations and various other public service announcements including AMBER alerts. While DMSs are intended to improve the efficiency and safety of road networks, little has been done to study the effect of the signs on driver safety. The purpose of this study is to determine whether or not drivers who are exposed to DMSs could be distracted by what the signs display and eventually be involved in an accident.

In the State of Maryland, the State Highway Administration's (SHA) Coordinated Highways Action Response Team (CHART) operates nearly 184 DMSs. The signs located on major highways and arterials are often used to inform motorists of delays, incidents, road closings and recently real-time travel times.

The accident and log of messages data in the study period was acquired from the Center for Advanced Transportation Technology (CATT) Laboratory at the University of Maryland, College Park and from Coordinated Highway Action Response Team (CHART) reports. The database was filtered and cleaned up. The DMS inventory was also provided through the CATT Laboratory. The DMS types in this research include permanently mounted overhead, roadside models and portable signs that are operated by CHART or Maryland Transportation Authority (MdTA). The roadway network map and AADT of roadway segments were obtained from Maryland Department of Transportation, State Highway Administration (SHA) and weather conditions databases were acquired from DOT archived data.

The accidents along with DMS locations and AADT database are projected onto Maryland roadway map in ArcGIS 10.1. An impact area is defined to perform spot analysis to evaluate whether DMSs influence on drivers' operational performance.

A case study is performed on Interstate 95 in Maryland which is regarded as a major highway. A sample of 70 road segments is chosen based on homogeneity in geometry. Regression analysis is performed based on the fact that the segment is an impact area or not, the segment includes interchanges or not and what the AADT of the segment is. Besides, an unbalanced two-way ANOVA is used to compare mean accident rate in impact areas and other segments.

The study area is divided into 5 regions and the nearest central weather tower station in each region is assigned to represent the weather condition in each region. The weather database is accumulated for the four-year study period and then joined to the main database based on closest weather tower station to the time and location of accident. The matching process is performed using SQL queries coded in C++.

The message log database is imported in SQL server along with the main database. For each accident if it is located in impact area, the assigned DMS is matched with the message displayed at the time of occurrence of accident. Likewise, the matching process is conducted using SQL queries coded in C++.

The integrated database was analyzed in several aspects. To determine the effects of DMSs on occurrence of accidents, accident rates in DMS impact areas and adjacent segment were compared using paired t-tests.

An on-and-off study is conducted to compare the results for the previous study. The difference in accident rates is tested on two DMS operation status, when they display messages and while they are blank, using one-way ANOVA with pairwise comparison test.

Ultimately statistical analyses on DMS characteristics, message types, weather conditions and accidents in impact area are performed.

The finding and methods of this research could be applicable for state officials and transportation and ITS agencies to analyze, evaluate and improve their DMS operations. This thesis focused on DMS operation in the state of Maryland and the methods employed for evaluation are extendable to other locations.

1.2. Organization of the Thesis

This thesis comes in five chapters. Chapter 2 reviews the literature on DMS operation, design and type of the messages that are displayed on DMSs. Chapter 3 is on the driver behavior, response to messages and localized safety impacts of these signs. It provides a comprehensive review on study methods and research to evaluate effectiveness and safety impacts of DMSs. Chapter 4 investigates the possible relationship between DMSs and occurrence of road accidents, and describes the motivation and methodology of this thesis along with all analysis and results. The results of the study and suggested future research are given in Chapter 5.

Chapter 2: Background and Literature Review

2.1. Dynamic Messages Signs

Maryland Manual on Uniform Traffic Control Devices defines Dynamic Message Signs as ”A sign that is capable of displaying more than one message, changeable manually, by remote control or by automatic control. These signs are called Dynamic Message Signs in the National Intelligent Transportation Systems (ITS) Architecture”. Dynamic Message Signs (DMS), also known as Variable Message Signs (VMS) or Changeable Message Signs (CMS), can be used by transportation authorities and operating agencies to disseminate travel information on a near real-time basis.

DMSs are valuable instruments and according to Deployment Tracking Database of Federal Highway Administration, it is estimated that more than $330 million has been spent in the deployment of DMSs in the United States (Dudek, 2008). The main goal of DMSs is to enhance motorist safety and provide real-time traffic information to motorists allowing them to make intelligent travel decisions ahead.

2.2. DMS Process and Operations

The information displayed on DMSs is gathered from a variety of traffic monitoring and surveillance systems and means including video detection systems, loop detectors, automatic vehicle identification transponders and toll tags and is reported to Traffic Management Centers (TMC). Travel time messages is derived by applying an algorithm which calculates the distance covered to determine the estimated travel times from a DMS to specific destination. The destination is usually considered as a major intersection or interchange. In most jurisdictions the travel time information is posted during morning and evening peak travel times and the system is generally timed to begin and end at a certain time of day. The TMC operator is responsible for monitoring, interpretation and decision making for posting the messages.

2.3. DMS Types

Dynamic Message Signs can be divided into permanent and portable with respect to installation. They also can be equipped with beacon and/or can have flashing messages.

2.3.1. Portable vs. Permanent Signs

DMSs can be fixed (overhead or roadside) or portable. Either fixed location or portable DMSs are used to support incident management and informative functions. Fixed DMSs can be deployed above the arterials and highways, bridges, tunnels or toll plazas. The portable truck or trailer mounted DMSs are sometimes dispatched by highway agencies to warn drivers of incidents such as accidents or work zones in the areas where permanent DMSs are not available or nearly enough to inform motorists to reduce speed and prevent secondary accidents. Trailer-mounted DMSs are used to alter traffic patterns near work zones and to manage traffic in special occasions such as sporting events, natural disasters and other temporary changes in normal traffic patterns. Most of manufacturers produce trailers that comply with the National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) to allow the portable trailer to be integrated with an intelligent transportation system. Trailer-mounted DMS signs can be equipped with radar, cameras and other sensing devices as part of a smart work zone deployment. Figure 2.1 shows fixed location and portable DMS signs.

Figure 2.1. Fixed location vs. portable DMSs

2.3.2. Dynamic Features

DMSs can be equipped with flashing beacons, which are typically installed on top of the message panel. They are usually yellow in color and should meet the requirements as commanded by NTCIP communications protocol in size and shape. The displayed messages on DMSs can also be flashing or blinking especially in the school zones, but since flashing line messages might have an adverse effect on comprehension of messages (Dudek, 2005), these types of messages are not very common.

2.4. Message Types

DMSs warn motorists regarding different situations and provide real time information on traffic, roadway and environmental conditions, location and expected duration of incident related delays, alternate routes for a roadway closure, redirected routes for diverted drivers and traversable shoulders in the event of a major incident to restore the traffic flow safely (Farradyne, 2000).

They are primarily used to display the following messages (Dudek, 2008):

- *Random and unpredictable situations* such as crashes, stalled vehicles, spilled loads
- *Temporary and preplanned activities* such as construction, maintenance or utility operations
- *Adverse environmental situations* such as fog, floods, ice and snow, etc.
- *Special events* such as road closures because of sport games and parades
- *Traffic flow operational initiatives* such as high occupancy, reversible, exclusive or contraflow lanes.
- *Certain design features* such as drawbridges, tunnels and ferry services.
- *Travel-time information*
- *AMBER* (America's Missing: Broadcast Emergency Response) alerts to help locate missing people

Ridgeway categorizes messages into three types. The types are as follows: Danger/ Warning Messages, Informative/Common Road Conditions and Regulatory/Non-Traffic Related. Table 2.1 shows type and example of messages in this classification.

Table 2.1. Message Categorization

Message Category	**Examples of Displayed Messages**
Type 1: Danger/Warning	Incidents, Disabled Vehicles, Non-recurring Slow-Downs, Roadway Debris, Unplanned Lane/Tunnel/ Bridge Closures
Type 2: Informative/Common Road Condition	Roadwork Closures, Major & Minor Delays, Congestion, Travel Time, Other travel related messages (Fog, Ice, Snow Plowing, Major Events)
Type 3: Regulatory/Non-Traffic Related	Work Zone Speeds, Seatbelt Use, Cell Phone Regulations, Motorcycle Awareness, Amber Alerts, Homeland Security Messages

2.5. Danger/Warning Messages

2.5.1. Incident Messages

One of the main functions of DMSs is to alert motorists of lane closures due to traffic incidents and accidents as unexpected situation to reduce roadway capacity. The message can be displayed due to any traffic incident; however no message should be displayed if the sign is at such a distance from the affected area that full capacity will be restored before motorists reading the sign would be impacted. Conversely, if the incident is confined to an adjoining route such that motorists in that route would be affected, a message should be displayed. Depending on the location, severity and duration of the incident, messages may be displayed up to several hundred miles in advance of the incident. If a situation arises whereby multiple incidents are downstream from a sign, DMS shall alert motorists to the closest incident unless conditions warrant otherwise (NJDOT, 2008).

2.5.2. Road and Vehicle Unpredicted Condition Warning Messages

These types of messages inform drivers of special issues with respect to road and vehicle conditions including changes in roadway alignment or surface conditions, disabled vehicle, vehicle restrictions and advance notice of new traffic control device installation (Walton et al, 2001).

2.6. Informative/Common Road Condition Messages

2.6.1. Travel Time Messages

These types of messages inform drivers in five ways:

1. Travel time on freeways which is the time in minutes required to traverse from one specified location to another

2. Comparative travel times on the freeway and alternate route

3. Time saved by taking an alternate route

4. Delay on the freeway

5. Delay avoided by taking the alternate route

2.6.2. Congestion Messages

DMSs are used to present information on traffic conditions when the freeway becomes congested. The problem regarding these messages involves the large continuum of possible traffic operational conditions that are difficult to describe on DMSs. In jurisdictions where quantitative travel time information is not available, terms such as “Heavy Delay” and “Major Delay” are often used. Little information or guidance exists on how these terms are defined. However, according to the Dynamic Message Sign Message Design and Display Manual, the average motorist in Texas interprets “Heavy Delay” as being between 25 and 45 minutes while a “Major Delay” is interpreted as a delay greater than 45 minutes. Similarly, a study in England to determine driver response to Dynamic Message Signs found that “Long Delays” were interpreted as delays between 35 and 47 minutes, while “Delays Likely” indicated a 10 to 31 minute delay. In contrast, the Minnesota Department of Transportation’s Guidelines for Changeable Message Sign (CMS) Use specifies that a “Major Delay” is not indicative of an amount of time but rather an incident causing more than 2 miles of traffic backup. These conflicting definitions alone demonstrate the need for high quality evaluation of DMS messages and the conditions to which they correspond (Fish et al, 2012).

2.6.3. Queue Warning Messages

Queue warning messages have been employed in Germany on several motorways. The queue warning messages vary in appearance, scope and complexity. A queue warning system uses a small roadside DMS with flashers to indicate the length and location of the queue. Germany Transportation Policy strongly emphasizes on comprehensive communication of the queue warning on the message signs using minimal wording and simple imagery. Benefits gathered from the German queue warning system include fewer incidents, reduced incident severity, closer headways, greater uniformity on all driver speeds and a slight increase in capacity (Bolte, 2006). Figure 2.2 depicts a dynamic queue warning message sign.

Figure 2.2. A Queue Warning Message

2.6.4. Weather-Related Messages

One of most common uses of DMSs is to display weather information that affects traffic. DMSs are used to advise motorists of severe weather or environmental conditions in the area, especially the situations which requires a change in the driving behavior of motorists (NCDOT, 1996) and (ORDOT, 2000).

2.6.5. Railroad Crossing Messages

One of the applications of DMSs is where roadway and railroad meet. According to Finely et al. (2001), since traffic conditions can also be affected by rail systems, railroad grade crossing information can be available via DMSs. An example of application of

DMSs in railroad crossing area is in San Antonio, where displaying the real time information on these messages allows drivers to alter their routes to avoid a lengthy wait for a crossing train.

2.7. Regulatory/Non-Traffic Related Messages

2.7.1. Public Service Announcement Messages

The use of DMSs for Public Service Announcement (PSA) is accepted by some agencies; however the type of messages that are permitted depends on each jurisdiction. PSAs include brief messages that do not require an immediate response but encourage drivers to alter a future driving behavior. Since PSAs do not provide drivers with real-time safety or travel efficiency information and usually are not associated with any urgent response, these messages are generally given low priority. PSAs provide motorists with information that can be given more effectively through other methods such as media campaigns or pamphlets (NCHRP, 2008). Another argument in support of not displaying public service announcement messages is the concern that motorists who continually travel a specific route will become accustomed to them and then begin to ignore the DMSs. For example, in State of Oregon Department of Transportation the very lowest priority is given to PSAs and they are displayed only in off-peak periods for a maximum of 5 hours a day and 5 days a month. In addition, these messages are generally restricted to permanent DMSs and not permitted on portable DMSs (ORDOT, 2000).

2.7.2. AMBER Alerts

AMBER alerts are notification programs to help locate missing children believed to have been abducted. The Emergency Alert System (formerly known as the Emergency Broadcast System) is used to alert the public by means of television and radio in the event of an AMBER alert (NCHRP, 2008). America's AMBER Plan Program through which emergency alerts are issued to notify the public about potential abductions of children is voluntary. Federal Highway Administration notes that DMS signs are not always the most effective or safest method to disseminate information related to child abductions and just a limited amount of information can be conveyed on them. When there is a need to provide extensive information to motorists, FHWA states that it is critical that other types of traveler information media such as 511, HAR, informative websites and commercial radio be used and DMSs play a supplementary role besides these media.

2.8.Inappropriate uses of DMSs

A national policy on DMS use and message design does not currently exist and transportation authorities are responsible to create and implement their own guidelines on the use, location, operation and evaluation of DMSs in their area. Mounce et al. (2007) assessed current DMS applications and practices based on a National literature reviews and agency surveys and found that majority of respondents in the survey believed that one of the major benefits of DMS is to provide timely and important information about the travel routes. The survey revealed that although most DMS applications are considered effective, there are some sources for concerns among the respondents, including information overload, adverse traffic impacts and lost motorist confidence. The results of the survey also indicated that although DMS evaluations are generally conducted in conjunction with an entire ITS evaluation, very little has been done regarding the evaluation of DMS's and special considerations should be given regarding the unique ability of DMSs as well as the message content, location and evaluation of DMSs to aid in creating successful DMS systems.

According to Mounce et al. (2007) all messages are prioritized by the following order:

*1. Safety related***:** messages that are directly related to safety are given first priority for display. Examples of this type of messages include winter traction device requirements, mountain pass information or flammable restrictions.

*2. Roadway closures***:** DMSs are used to display road or ramp closures, regardless of the reason for the closures (accident, construction, weather, etc.).

*3. Minor traffic impacts***:** DMSs are used to display information about minor traffic impacts, such as construction lane closures, blocking incidents and delay information.

4. Public text messages: as mentioned in the previous section, the least priority messages displayed on DMSs are transportation related Public Service Messages. These messages do not directly impact motorists and therefore are not critical to the safe and efficient operation of the transportation system. Examples of these messages are Click It or Ticket, Rideshare information or announcements about traveler information phone numbers like 511.

5. Test messages: these types of messages are used to perform sign operation or maintenance checks and to ensure proper operation of new DMSs.

2.8.1. Traffic-Related Messages

The Kentucky Transportation Center notes several inappropriate usages of DMS (Walton et al., 2001). A particular inappropriate application of DMS is the use of DMS messages to restate or replace required permanent signage. This could result in serious problems of information overload and driver inattention to DMS. Specifically, DMS messages should not replace static signs, regulatory signs, pavement markings, standard traffic control devices, conventional warnings or guide signs.

2.8.2. Non Traffic Related Messages

Policies regarding the display of non-traffic-related messages on DMS are not consistent. The *Manual on Uniform Traffic Control Devices* states that DMSs should not be used to display information other than regulatory, warning and guidance information related to traffic control. Some policies state that messages displayed on DMSs must require motorists to take an action or alter their driving behavior (NCDOT, 1996) and (Johnson, 2001). There is a consensus that DMS should not be used to advertise commercial events or entities. Additionally, tourist information should not be provided via DMS (NCDOT, 1996; ORDOT, 2000; Walton, 2001; and Jones et al., 2003).

2.8.3. Sources to Disregard the DMSs

Dudek (2008) further specifies DMS problems that lose the motorists' confidence:

- Displaying inaccurate or unreliable information
- Displaying information too late for drivers to make an appropriate response
- Displaying messages that drivers do not understand
- Displaying messages that are too long for drivers to read
- Not informing drivers of major incidents
- Informing drivers of something they already know
- Displaying information not related to environmental, roadway or traffic conditions or routing, and
- Displaying garbled messages

If any of these errors are committed by DMS operators, motorists are likely to disregard these signs. Influencing the decisions of motorists is necessary for a DMS to be effective.

2.9. Location of Dynamic Message Signs

DMS locations are generally established through prior experience with the local traffic problems. Recently researchers have experimented with computer programs that can more precisely locate signs. These methods have not yet been implemented by any local traffic management agency responding to the survey. The locations of DMSs are often determined through unwritten current practice and general policies. Agencies seldom implement methods to ensure that specific DMS locations are optimal. Two applicable methods for optimizing DMS locations include genetic algorithms and integer programming. Abbas and McCoy (1999) have researched the use of genetic algorithms for this purpose. They indicated that their decision to implement genetic algorithms was based on several factors including the fact that Genetic algorithms give several solutions, not just one “best” solution and additionally, the constraints required in genetic algorithms are less than those necessary to find an integer programming solution (Abbas et al., 1999).

Chiu et al. (2001) researched the use of integer programming to optimize DMS locations. With a given number of DMSs, possible locations were determined and analyzed. Optimal locations were chosen so that the long-run expectation of benefits was satisfied under stochastically occurring incident scenarios. They stated that the main benefit of correctly locating DMSs was the reduction in total user travel time. Implementation of the programming required numerous inputs to describe geometry and traffic patterns of the highway network. The problem was simulated using a dynamic traffic assignment algorithm, which aided in determining the effectiveness of DMS locations. It was necessary that each location had a high probability of capturing the randomly occurring incidents and then could effectively divert traffic. The final solution generated by the integer-programming model determined the optimal location for all incident scenarios on the system. The solution might not be optimal for an individual incident (Chiu et al., 2001).

Chiu and Huynh (2007) combined a mesoscopic dynamic traffic assignment simulation with a tabu search heuristic to optimally locate DMSs. Incidents were randomly generated using a Monte Carlo scheme and some drivers would switch routes if their path encounters an incident and a DMS sign; based on the resulting flow patterns, a set of DMS locations was determined to optimize some measure of effectiveness (Chiu et al., 2007).

Huynh et al. (2003) used a similar analysis framework to find the optimal locations of portable DMSs in a real-time framework using the G-D heuristic. Although the simulation approach allowed a rich set of traffic and behavioral impacts to be modeled, the computational burden associated with many simulation runs on a large network could be troublesome. This limitation was realized by Henderson (2004), who adopted a static equilibrium framework for DMS location, together with a discrete choice model to determine the proportion of drivers who switch routes in response to learning of an incident. Henderson (2004) developed and compared several heuristic techniques including a genetic algorithm and a greedy approach based on sequential location. While computationally faster, the approaches implicitly assumed that drivers did not anticipate receiving information which means their initial route choice was not affected by the DMS locations, so links with a DMS did not "attract" drivers who anticipate benefitting from that information, for instance (Hendeson, 2004). Although this distinction may seem subtle, this anticipation effect could lead to radically different route choices for rational drivers, even from the origin (Boyles, 2006).

2.10. DMS Performance Metrics

Tarry (1996) defined performance indicators expressly for evaluation of DMSs. Table 2.2 presents examples of performance indicators for DMSs. To produce appropriate driver response, the messages displayed on DMSs must be meaningful, accurate, timely and useful. According to Dudek (2006), if the messages displayed on DMSs do not have adhered to the guidelines of Dynamic Message Sign Message Design and Display Manual, operator's credibility is lost.

2.11. Studies Related to Designs of DMSs

Extensive human factors and traffic operations research has been previously conducted to develop fundamental principles and guidelines for DMS message design including alphanumeric messages, graphics and symbols. Using these fundamental principles, guidelines for effective message design and display for TxDOT have been published in Report 0-4023-P3 *Dynamic Message Sign Message Design and Display Manual* (Dudek, 2006). The use of graphics or symbols on DMSs has been employed in many European countries such as Germany and Spain but has not yet gained widespread popularity in the United States.

Nygårdhs (2011) reviewed the literature of Dynamic Message Signs focusing on a large number of studies done from 2006 to 2009. This literature review reached the following findings about design of DMSs:

Table 2.2. Example Performance Indicators for Dynamic Message Signs

Evaluation Category	**Indicators**
Technical Analysis	• Reliability and correctness of information displayed • Appropriateness of plans • Operator interface usability • Sensitivity to errors in inputs • Level of operator intervention needed
Impact Analysis	• Degree of diversion at nodes • Reduction in delays and extent of queuing • Change in travel time on individual routes • Change in total travel times and journey distances in the network • Reduction in the duration of congestion • Reduction in emissions • Driver response to: range of information types, travel cost differences on alternative routes and driver familiarity with the network • Reduction in traffic diversion through urban areas or on the undesirable routes • Number of accidents
Socioeconomic Analysis	• User cost-benefit analysis of performance network • Impact on non-road users
Legal/Institutional Analysis	• Legal/institutional conflicts
Public Acceptance Analysis	• User attitudes to DMSs • Non-user attitudes to DMSs

1. Graphic-aided messages are significantly better than text-only messages in terms of preference, response time and accuracy and should be used as much as possible.
2. Red color is not recommended for DMS messages.
3. Older drivers' performances were significantly improved by graphic-aided messages.

4. Graphic-aided DMS messages enhanced message comprehension time for non-native English speakers.
5. More research is required to find out the proper specifications and design guidelines of these graphical images to be used on DMS messages.
6. The number of lines on DMS should be kept to a minimum.
7. Bilingual signs should only be used when absolutely necessary.
8. If bilingual signs are used, different colors or type fonts should separate the languages.
9. The number of information units may be better correlated to DMS reading time than the number of lines displayed.
10. A blank “off-screen” with short duration may enhance information processing when successive DMS frames are used.
11. Right-justified text on DMS should be avoided.
12. Abbreviations could decrease understanding of DMS if they are not very commonly known.
13. Luminance class L3 is preferable for symbols on DMS.
14. A three diode symbol thickness leads to better legibility than one or two diodes thickness.

Chapter 3: Driver Response Behavior to Messages and Localized Impact of DMSs

3.1. Driver's Response to Displayed Messages

The existing studies for evaluating driver response to DMS messages mainly focus on DMS objectives of route choice guidance and improving road network performance and speed slowdown in correspondence to messages. From the literature review, it is evident that the acceptance of DMS is associated with the travelers' perception and their subjective attitudes towards information and its presentation. Most of the studies have found that demographic and socio-economic characteristics are important factors in assessing the satisfaction of the travelers towards a novel traveler information technology like the DMS signs. However, travelers also have specific preferences about the formats and contents of messages and information posted on the DMS. While most of the studies show that the travelers adopt DMSs for their traveler information needs, DMS do not necessarily change their travel behavior. Network familiarity, proactive information and advisory information have been found to have different effects at different locations of the study (Rogers, 2005). Multinomial and binomial logit models have been predominantly used to model the diversion behavior under traveler information scenarios with DMSs. The effect of DMSs has been found to vary in different study sites.

Wendelboe (2008) performed a research on driver response to DMS messages in 2008 based on driver surveys. Table 3.1 shows the results and conclusions of the surveys.

The literature review conducted by Nygårdhs (2011) concluded the following findings about the issue of DMSs and driver reaction to messages:

Table 3.1. Results from driver surveys (Wendelboe, 2008)

Respondents who:	Percent
Understood variable speed limits (VSL) correctly	82%
Perceived queue information correctly	88%
Perceived queue information correctly when information about distance to the rear end of the queue was added	61%
Had a generally positive attitude to VSL	84%
Thought VSL had a positive effect on traffic flow	58%
Thought VSL had a negative effect on traffic flow	12%
Thought VSL had a positive effect on traffic safety	33%
Thought VSL had a negative effect on traffic safety	3%
Had a generally positive attitude to queue information	86%
Had a generally negative attitude to queue information	5%

1. DMSs are effective in rerouting traffic.
2. Supplementary information of DMSs may not enhance behavior concerning compliance.
3. Reading and processing text messages on DMS leads to speed reductions.
4. Displayed delay times on DMS are correlated to diversion patterns.
5. Factors correlated to unwillingness to divert from the freeway are driving employer-provided cars, frequency of driving on the freeway and being middle-age.

There is some concern that more frequent use of non-incident and non-roadwork transportation-related messages can compromise the credibility of the DMS's. If DMS's distract drivers from more critical tasks while traveling at prevailing speeds or if the messages are erroneous or outdated, then driver acceptance can be compromised. In addition, if the messages are too long, complex and/or confusing to read and comprehend, drivers may reduce speed to read the messages and this could result in a potential safety problem (Dudek, 2008).

3.1.1. Route Diversion in Response to Messages

Many researchers have studied drivers' attentions and responses to DMSs. To evaluate the effectiveness of DMSs for route choice guidance, some researchers have tried to estimate a route choice model for predicting how drivers respond to the information provided by DMS and whether the drivers will divert to avoid an incident or congestion on road. Many researchers used surveys or simulations to gather the data regarding the behavior of motorists in response to DMS messages. The surveys used revealed preference or stated preference questionnaires of hypothetical situations (Khattak et al., 1993, Wardman et al., 1998, Abdel-Aty, 2000, and Hao et al, 1999). Fish (2012) presented empirical evaluations of the quality and effectiveness of highway DMSs and introduced Bluetooth sensor technology as a new method for evaluating messages posted on DMS for both the accuracy of the content as well as the influence they may have on travel behavior. The results showed that diversion messages are effective in route choice decisions of motorists.

The study of incident impacts on driver behaviors have focused on changes at the strategic behavior level, particularly changes in the route choice behavior. Incident messages include accident, lane closures and traffic merge messages. Several researchers have used the stated preference approach in an attempt to determine the percentage of travelers changing trip decisions in response to information disseminated by ATIS devices such as DMSs. The studies concluded based on this type of surveys that the disseminated information can result in up to 60-70 percent of the freeway traffic exiting the freeway ahead of a bottleneck, like an incident location and as a result 30 to 40 percent reduction in congestion (Barfield et al., 1989, Benson, 1996, Madanat et al., 1995, and Chatterjee et al., 2002). However, limited information is available about the actual diversion due to traveler information as reflected by revealed preference or field measurements. Several European field studies have found that DMS compliance rates range between 27-44% (Tarry et al., 1995). Knopp et al. (2009) found that for major incidents, up to 50% of the travelers take another route. Schroeder et al. (2010) investigated the impacts of existing message strategies to determine messages that maximize diversion for specific circumstances and to develop new messages for future deployment.

Ullman et al. (2005) evaluated DMS messages to determine which displayed message drivers found the most effective in an emergency situation. The study concluded that during emergencies, DMS messages should provide meaningful and straightforward messages that can be read and responded to quickly because their impact on drivers can be huge.

In a questionnaire survey, Benson (1996) investigated whether drivers noticed and thus responded to DMSs. The author found that about 20% out of 500 subjects ignored active DMSs while driving. Interview surveys conducted by Bonsall (1993) in Paris revealed that 97% of the drivers knew that DMSs existed, 84% identified DMSs as providing very useful information and 46% had at least once detoured accordingly.

Peng et al. (2004) conducted a similar study in Wisconsin. The results indicated that 62% of the drivers responded to DMS messages more than once per week and 66% of them changed their route at least once per month due to the posted message.

Khattak (1993) suggested that diversion behavior was influenced by the accuracy and detail of information, including travel times and alternate choices and knowledge of nature of the event and actions to clear it in case of incidents.

The study done by Roshandeh and Puan (2009) attempted to utilize archived traffic data from a freeway area in Kuala Lumpur to assess the accuracy with which DMS display travel time estimates and driver response to display messages of varying lengths and formatting. Results showed that usage of DMSs reduce the average travel times during the duration of the incident until the clearing of the resulting congestion by a significant amount.

Levinson and Huo (2003) conducted a on and off study using data from inductive loop detectors placed on different networks located in the Twin Cities of Minneapolis and St. Paul, Minnesota. The purpose of this study was to measure the effectiveness of the DMSs. Using the traffic flow and occupancy data, a discrete choice model was developed to forecast the percentage of vehicles that diverted to alternative route based on the message displayed. Results showed that drivers' diversion increased when a warning message about the traffic conditions was displayed and that DMSs can reduce the total delay.

Peeta (1991) found that the location of an incident and its duration also affected route choice. In a survey conducted in Virginia, it was found that drivers' characteristics such as age, education, income and sex have no significant influence on their attitude towards DMS messages (United States Department of Transportation, 2002). In Dallas, 71-85% of surveyed drivers used the recommended route. The factors having influence on diversion include traffic conditions on the alternate routes, familiarity with the alternate route, and confidence in the information (United States Department of Transportation, 2002).

Yang (1993) also found that the route choice behavior was affected by the characteristics of the alternative routes. The results of this study which was based on loop detector data, indicated that DMS could affect vehicle diversion significantly, especially during congested times. DMS's had more influence on drivers during morning peak hours than during evening peak hours. According to a survey conducted by Huo and Levinson (2002), drivers are more willing to divert if there are fewer traffic stops on the alternate routes and if they are familiar with the alternate routes. Their study also showed that young, male and unmarried drivers were more likely to divert.

3.1.2. Speed Reduction in Response to Messages

Benekohal and Shu (1992) performed research in university of Illinois to evaluate driver behavior responses to speed reduction messages in construction work zone areas. They employed statistical analysis techniques for treatment/control conditions when DMS sign is turned on and off. They found that displaying the speed limits on DMS was effective in reducing the average speed. Their study showed that displaying messages reduced speed of cars immediately after passing the sign, but not at a point far from DMS. Cars and Trucks reduced their speed by as much as 5 and 4 mph respectively near the DMS.

3.2. Effect of DMSs Design on Driver Response

Studies show that DMSs with different format and design could have different effect on driver behaviora. This section reviews the research which compared driver response to text versus graphic and flashing versus static messages.

3.2.1. Text-based vs. Graphic-aided Messages

Wang et al. (2007) conducted a study on the use of graphics on DMS and found that most drivers preferred graphics over text and responded faster to graphic-aided messages than text-only messages. Due to these findings, it is suggested to use graphics in some advisory signs to help enhance drivers' understanding and responses to messages and improve the effectiveness of these signs.

In another similar research, Bai et al. (2011) suggested that the traditional text-based messages have several limitations such as confusing drivers and delaying their responses during driving, being difficult to read for older drivers and non-English-speaking drivers and having a short range of legibility. Bai et al. (2011) state that use of graphic-aided and graphic messages on portable DMSs have many advantages over text-based ones based on a number of previous laboratory simulation experiments. They used field experiments and driver surveys to determine the effectiveness of a graphic-aided and graphic portable DMSs on reducing vehicle speed in the upstream of a one-lane two-way rural highway work zone and compared the effectiveness of text, graphic aided and graphic portable DMSs on reducing vehicle speed in a highway work zone in Kansas based on regression models of the relationship between mean vehicle speed and distance under the three conditions. The findings showed that:

1. Text, graphic-aided and graphic portable DMSs resulted in a mean vehicle speed reduction of 13%, 10% and 17%, respectively.

2. Graphic-aided portable DMS reduced mean vehicle speed more effectively than the text one from 1,475 feet to 1,000 feet in the upstream of a work zone.

3. The majority of drivers understood the work zone and flagger graphics and believed the graphics drew their attention more to the work zone traffic conditions.

4. Most of drivers preferred the information to be presented in the graphic-aided format.

3.2.2. Flashing vs. Static Messages

Based on the research performed by Dudek (2005), average reading times for flashing messages were not higher than for static messages. However, the results indicate that flashing messages may have an adverse effect on message comprehension for unfamiliar drivers. Average reading times for flashing line messages and two-phase messages with alternating lines were significantly longer than the alternative messages. In addition, message comprehension was negatively affected by flashing line messages.

3.3. Localized Impact of DMSs

3.3.1. Traffic Speed Slow Down for Perception of Messages

Oh, Hong and Park (2009) conducted a study with the aim of investigating drivers' (about 20-30 years old) behavioral responses to DMSs when reading and processing the messages in a DMS influence zone. Individual vehicle trajectories were studied via differential global positioning system (DGPS) and thereby speed and acceleration rates were used as surrogate measurements to represent driver behavior. The DMS influence zone was divided into five sections of 100 meters long. Results from ANOVA tests showed that the average speed and acceleration were statistically different in each section. It was found that drivers tend to reduce their travel speed while reading and processing DMS messages and increase speeds again after they finish reading the messages.

Rama and Kulmala (2000) investigated the effects of two DMSs on drivers' car-following behavior. Results showed that a sign for slippery road conditions reduced the mean speed by 1-2 km/hour in addition to the decrease caused by the adverse road conditions.

In study performed by Wang et al (2007), the effects of DMS messages on traffic approaching and passing the signs were investigated. Traffic data gathered by several Mobility Technology Units (MTUs) near DMSs along I-95 in Rhode Island were analyzed. The purpose of the research was to understand the effects of various DMS messages on the speed variations on traffic approaching and passing the signs through traffic data analysis. With a positive correlation found between certain posted DMS messages and traffic slow-downs, the study next explored means to better the design and display on DMSs. A questionnaire survey was developed to find the general and specific causes of slow-downs. Survey results indicated that DMS was among the top few that caused drivers to slow down while danger warning messages attracted the most attention from drivers. It also showed that the majority of drivers reduced their speeds when approaching active DMSs while lengthy, complex or abbreviated messages caused further slowdowns. Their study also employed a computer based questionnaire survey and a driving simulation experiment to measure drivers' preferences and responses to various DMS displays and formats. The results showed that elder drivers exhibit a higher tendency to slow down.

In a recent study, Fish et al (2012) investigated 2,268 cases of message activation, removal and switching using RTMS speed data to determine whether DMS messages cause speed slowdown. The study confirmed that in some cases traffic streams decrease speed in response to message activation.

In a study conducted by Harder et al. (2003) a computer based driving simulation was used to test various message types to see whether a slow-down effect was evident. The results showed that 21.7% of participants slowed their speed by 13.9 mph as “AMBER” alert DMS messages were approached. Alternatively, when a “Crash” alert DMS message was displayed, 13.3% of participants slowed their speed by 12.7 mph.

In another study, Boyle and Mannering (2004) used a driving simulation to determine the impact of DMSs on drivers’ speed. While it was found that drivers did slow down when approaching active DMSs, the study also showed that drivers speed up to compensate for their speed reduction after passing DMSs. Furthermore, the study demonstrated that when drivers encountered a new DMS message, they were more likely to have a larger deviation in speed. This can mean that when a new message is presented on a DMS, drivers tend to notice the change in message and as a result more time is needed to process the information. Moreover, when a DMS is displaying the same message for a long period of time, drivers become familiar with it and thus less time is needed to read it.

It has been shown in several studies that the use of graphics to convey meaning on roadway signs provided many advantages over text-only messages. Graphic aided messages could be more easily and quickly identified compared to text-only messages from a further distance.

The fact that graphically presented information allowed faster responses than information presented by words was found by many studies (Bruce et al., 2000; Hanowski and Kantowitz, 1997; Staplin et al., 1990). Wang et al. (2007) conducted a study on the use of graphics on DMSs and found that most drivers preferred graphics over text and responded faster to graphic-aided messages than text-only messages. The use of graphics or symbols on traffic signs has been widely employed in European countries such as Germany and Spain to influence derivers’ route choices. All of these studies and practices indicated that by adding graphics, it might help enhance drivers’ understanding of and responses to DMSs and ease the slow-downs. Adding graphics to DMS messages could help enhance drivers’ understanding of and responses to those messages and reduce their speed variation while reading DMSs and might help eventually ease the slow-downs.

3.3.2. Driver Distraction and Collision Occurrence

Driver distraction plays a significant role in traffic safety. Driver distraction is a factor in one in four car crashes and of those crashes involving driver distraction; one in four involves distractions outside the vehicle (NHTSA, 2009). Few studies have been conducted on accident rates due to distractions associated with DMSs. Part of the reason is that unless there is a clear accident trend prior to a DMS, a definite accident rate formulation would be hard to determine. According to the Kiewit Center for Infrastructure and Transportation (2003) accident rates for a section of road can be determined by a ratio of accidents per million vehicle miles of travel. The normalized formula would allow comparing various accidents with respect to the rates of other stretches of roads that are not necessarily of the same length.

Many studies focus on the impacts of DMS on driver behavior and the potential benefit of using DMS to reduce downstream accidents. Chamberlain (1995) demonstrated that the use of DMS associated with a queue detecting system could reduce accidents for upstream drivers who otherwise would be unprepared for queues downstream. According to NHTSA's Distraction initiative, 20% of all accidents are related to some kind of distraction (2010). Many studies indicated that DMSs have attracted drivers' attentions from their driving (Wang et al., 2007). Since drivers are expecting useful information from active DMSs, they are slowing down to gain extra time to read and comprehend the messages. To compensate for their speed reduction, drivers speed up after passing DMSs.

Crashes are highly correlated to driving speed and this speed variation could pose a threat to other vehicles in the traffic and lead to crashes.

Erke et al (2007) conducted a field test and video observation study. In their research messages were set on and off to observe and compare driver behavior including route choice, speed and braking behavior between vehicles approaching the DMSs while they displayed messages and while they were left blank without message. Two DMSs were used in this study, which displayed road closure and recommendations for alternative routes. Speed measurements of 3342 vehicles showed large speed reductions and video observations showed that large proportions of vehicles braked while approaching the DMSs. This research states that speed reductions and braking maneuvers can partly be attributed to attention overload or distraction due to the information on the DMSs. Besides, a proportion of the speed reductions was due to chain reactions where one vehicle braked and forced the following vehicles to brake or change lanes in order to avoid collisions. Safety problems may result directly from distraction or indirectly from the reactions of the drivers to the distraction.

3.4.Summery

Many methods have been utilized in an effort to determine the driver response when approaching the DMSs. Surveys, simulators, video observation and loop detector data have been the most common of these methods in the past and have shown some promising results. Table 3.2 and Table 3.3 present a summary table for previous studies on driver response in correspondence to diversion and speed reduction messages, while Table 3.4 summarizes the reviewed literature on the localized impacts of the signs. This thesis uses the ground truth data integrated database to evaluate the impact of the signs on occurrence of road accidents.

Table 3.2. Literature Summary on Driver Response to Diversion Messages

Author	**Source**	**Year**	**Country**	**Study Approach**	**Results**
Fish et al.	TRB	2012	US, Maryland	Field Test/ Bluetooth sensors	• diversion messages are effective in route choice decisions.
Chen et al.	IWMSO 2008	2008	China, Beijing,	SP survey	• diversion increases as the traffic speed decreases. (<20 km/h). • 21.45% of drivers divert
Foo & Abdullahi	TRB	2008	Canada, Ontario	Field Test/Loop detector	• occurrence of a message change plays a vital role in influencing downstream diversion
Cheng & Firmin	12th IEE Int. Conf.	2004	UK, London	SP survey	• more exposure to DMS increases appreciation of the information displayed.
Peng et al.	Trans. Res. Rec.	2004	US, Wisconsin	RP survey combined with	• 75% are positive with usefulness of VMS. • 16% don't trust VMS information and don't

Author	Source	Year	Country	Study Approach	Results
				logit model	change their route.
Levinson & Huo	TRB	2003	US, Minnesota	Field Test/ Loop Detector	• a probit model to estimate diversion as a function of message content. • ahead warning is effective for diversion.
Chatterjee et al.	Trans. Res. Part C	2000	UK, Leeds	Survey, Logistic Regression	• location of incident and message content influence the probability of diversion.

Table 3.3. Literature Summary on Driver Response to Speed Reduction Messages

Author	Source	Year	Country	Study Approach	Results
Alm & Nilsson	Trans. Human Factors	2000	Sweden	Simulation	• all participants reduced their speed in response to incident warning messages
Luoma et al.	Trans Res. – Part F	2000	Finland	Simulation	• drivers reduced speed 1-2 km/h in response to a DMS warning of slippery condition

Author	Source	Year	Country	Study Approach	Results
Benekohal& Shu	Civil Eng. Studies	1992	US, Illinoise	Treatment control (DMS on and off)/ statistical analysis	• displaying the speed limits is effective in reducing the speed. • speed of cars reduces immediately after passing the DMS, but not at a point far from DMS. • cars and trucks reduced their speed by as much as 5 and 4 mph respectively near the DMS.

Table 3.4. Driver Distraction and Speed Slow Down for Perception of Messages

Author	Source	Year	Country	Study Approach	Results
Wang et al.	TRB	2009	US, Rhode Island	Survey	• DMS cause slowdown (specially danger warning messages). • lengthy, complex or abbreviated messages caused further slowdowns. • elder drivers exhibit a higher tendency to slow down

Author	**Source**	**Year**	**Country**	**Study Approach**	**Results**
Erke et al.	Trans. Res. Part F	2007	Norway, Oslo	Field Test/video observation (messages on/off)	• most of vehicles braked approaching the DMS. • messages causes distraction and leads to speed reduction and chain collisions and safety problem.

Chapter 4: Investigation on Possible Relationship between DMSs and Occurrence of Road Accidents

4.1. Problem Statement and Motivation of Research

While DMSs are intended to improve the efficiency and safety of road networks, as it was mentioned in the literature review, little research has been done to study the effect of these devices on driver safety. In spite of all advantages of DMSs, some issues regarding the disadvantages of real-time travel signs have emerged. The news in WTOP and NBC are examples of the opposing side which claim besides the fact that these devices are very expensive, they have adverse impact on drivers' distraction and speed slow down which may consecutively lead in occurrence of road crashes (HSM, 2010). The purpose of this research is to investigate the problem and determine if there is any meaningful relationship between occurrence of accidents and presence of DMSs in proximity to them.

For this study, accident data and DMS locations in the state of Maryland for a time period of 4 years from 2007 to 2010 are mapped in ArcGIS to determine accident pattern on the state highway network. Although general public acceptance to these messages is positive, some users and media outlets have raised concerns that DMSs cause vehicles to slow down and distract drivers which may result in congestion and safety issues. In order to investigate the claims, All 184 highway DMSs in State of Maryland are studied to evaluate the accident patterns in their proximity. The purpose of this study is to determine whether DMSs in Maryland highways produce significant localized safety issues. The data used and methods of research are described in detail in the following sections.

4.2. Methodology

4.2.1. Data Sources and Preparation

The data used to complete this research are collected from the Center for Advanced Transportation Technology (CATT) Laboratory in the Department of Civil and Environmental Engineering at the University of Maryland at College Park, Coordinated Highway Action Response Team (CHART) reports for regions within the District of Columbia in Maryland, and Maryland Department of Transportation, State Highway Administration (SHA) and DOT archived data. Figure 4.1 shows the databases and sources that are used in the research.

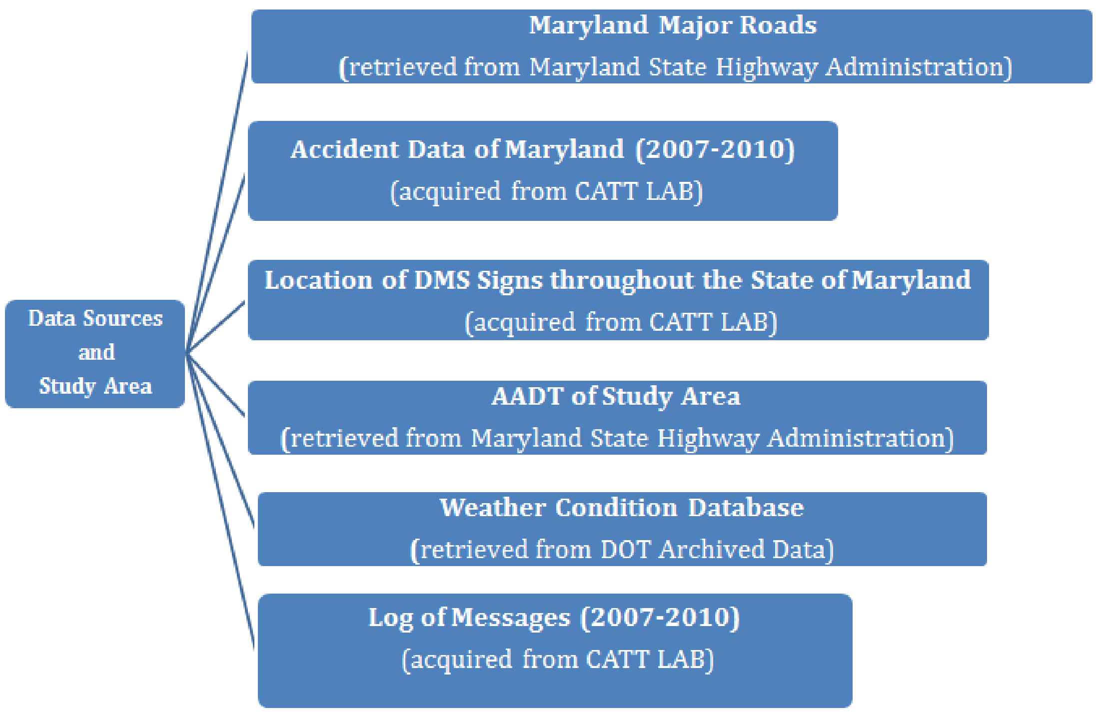


Figure 4.1. The databases and sources of data used in the research

The study area is set roadway network in State of Maryland. Figure 4.2 depicts the study area in the research.

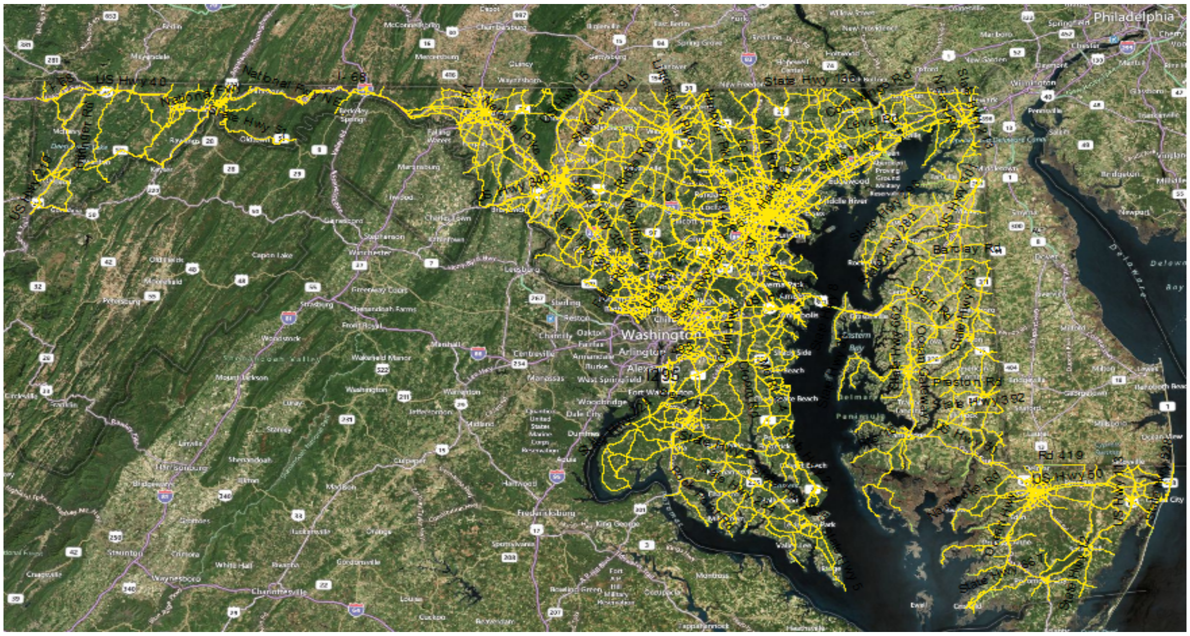


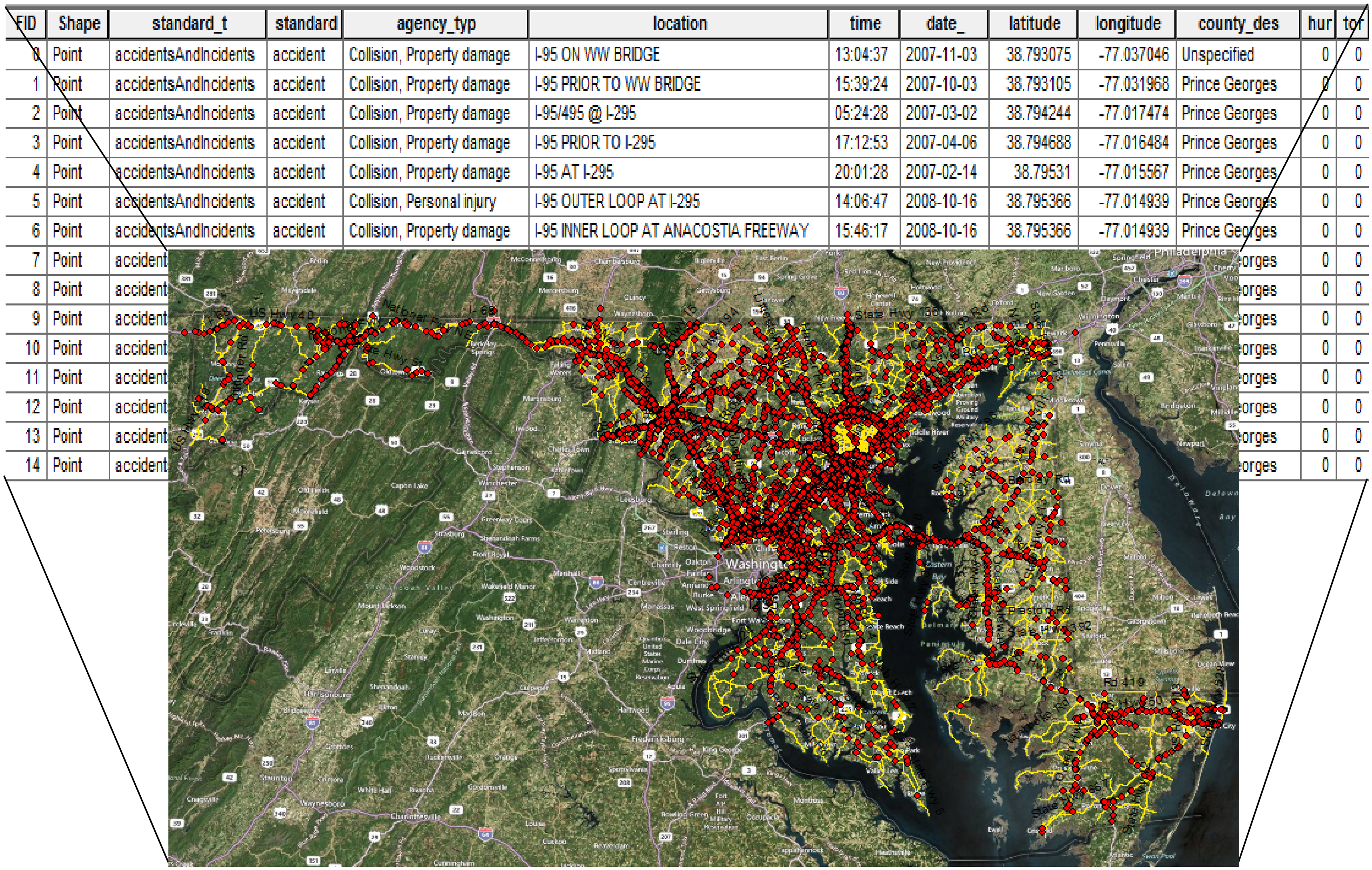
Figure 4.2. Study Area

4.2.2. Accident Database

The accident database included 38,718 records. A data cleansing process was conducted to remove data gap and outliers which resulted in a data set of 23,842 accident records for the four-year period of 2007 to 2010 in the entire State of Maryland. The data set consists of accident type (property damage, personal injury and fatality), geographical location, jurisdiction, time of accident and other related information. Due to confidentiality concerns, access to police records and accident causes was not possible.

Locations of accidents are pinpointed on road network map for further analysis.

Figure 4.3 shows the first shape of accident database and the locations of accidents projected on the road map.



FID	Shape	standard_t	standard	agency_typ	location	time	date_	latitude	longitude	county_des	hur	tor
0	Point	accidentsAndIncidents	accident	Collision, Property damage	I-95 ON WW BRIDGE	13:04:37	2007-11-03	38.793075	-77.037046	Unspecified	0	0
1	Point	accidentsAndIncidents	accident	Collision, Property damage	I-95 PRIOR TO WW BRIDGE	15:39:24	2007-10-03	38.793105	-77.031968	Prince Georges	0	0
2	Point	accidentsAndIncidents	accident	Collision, Property damage	I-95/495 @ I-295	05:24:28	2007-03-02	38.794244	-77.017474	Prince Georges	0	0
3	Point	accidentsAndIncidents	accident	Collision, Property damage	I-95 PRIOR TO I-295	17:12:53	2007-04-06	38.794688	-77.016484	Prince Georges	0	0
4	Point	accidentsAndIncidents	accident	Collision, Property damage	I-95 AT I-295	20:01:28	2007-02-14	38.79531	-77.015567	Prince Georges	0	0
5	Point	accidentsAndIncidents	accident	Collision, Personal injury	I-95 OUTER LOOP AT I-295	14:06:47	2008-10-16	38.795366	-77.014939	Prince Georges	0	0
6	Point	accidentsAndIncidents	accident	Collision, Property damage	I-95 INNER LOOP AT ANACOSTIA FREEWAY	15:46:17	2008-10-16	38.795366	-77.014939	Prince Georges	0	0
7	Point	accident								orges	0	0
8	Point	accident								orges	0	0
9	Point	accident								orges	0	0
10	Point	accident								orges	0	0
11	Point	accident								orges	0	0
12	Point	accident								orges	0	0
13	Point	accident								orges	0	0
14	Point	accident								orges	0	0

Figure 4.3. First shape of accident data and pointing location of accidents on road network map

4.2.3. DMS Database

The DMS inventory is acquired from CATT Laboratory. The DMS inventory includes all types of signs including permanently mounted overhead, roadside models and portable signs that are operated by CHART or Maryland Transportation Authority (MdTA). The DMS database with 184 records includes identification number, longitude and latitude, address location and type for all the 184 DMSs in the state of Maryland. Figure 4.4 shows the first shape of DMS data and its projection onto the road network map.

As mentioned earlier, associated with each accident is a geographic longitude and latitude which are used to join the accident and DMS databases. Likewise, each DMS is projected onto the same road network map from SHA database using their longitudes and latitudes. As shown in Figure 4.5, a network system is created with the three overlaid layers.

An impact area of 900 feet is defined for each DMS and in each DMS impact area, the sign was assigned to accidents within 900 feet of the DMS. The details on impact area definition will be provided in next section. Accidents in 900 feet proximity to DMSs were accounted as occurring in the impact area based on location field, visual judgment and direction of DMSs to mitigate GPS errors.

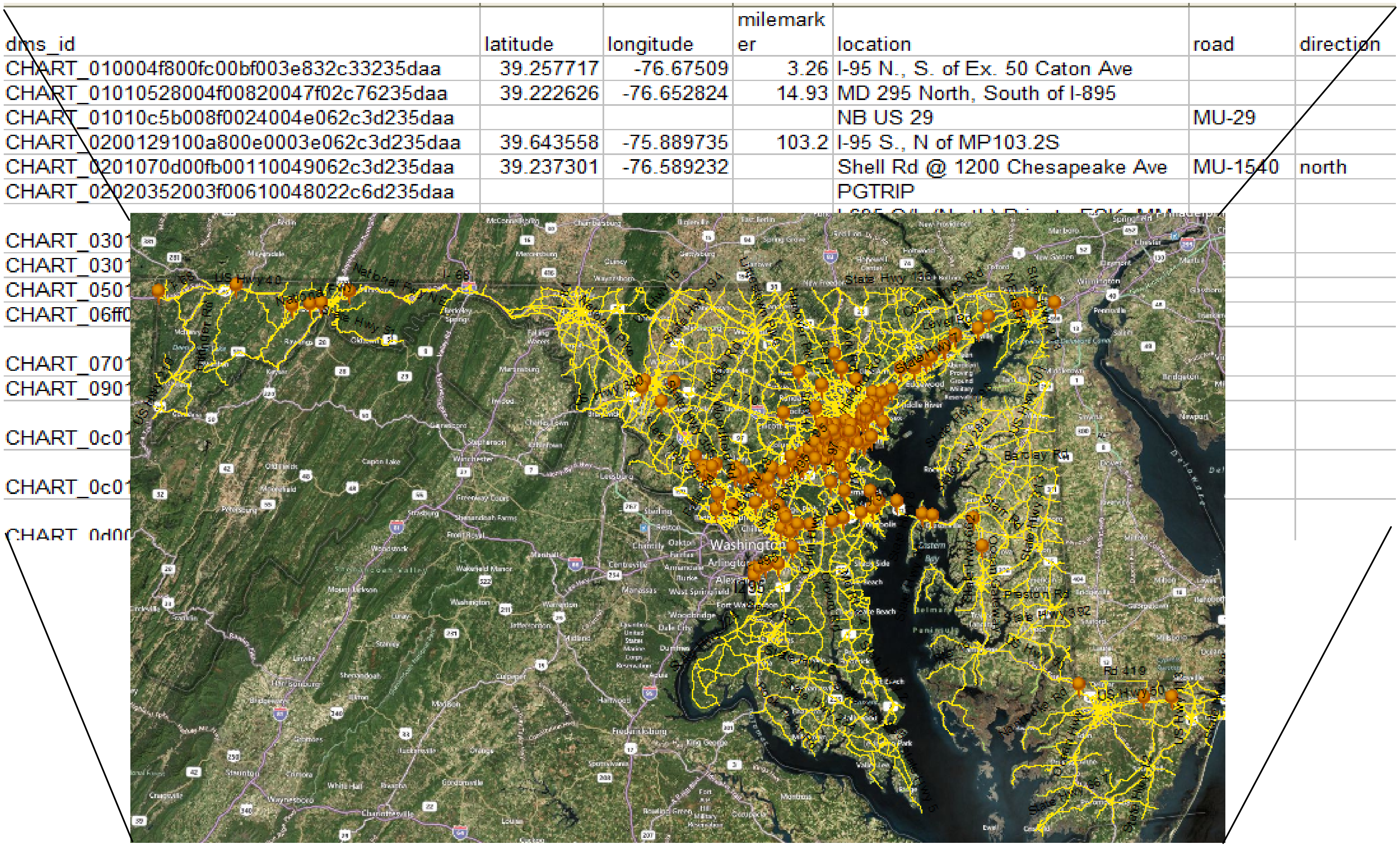


Figure 4.4. First shape of DMS database and projection to road map

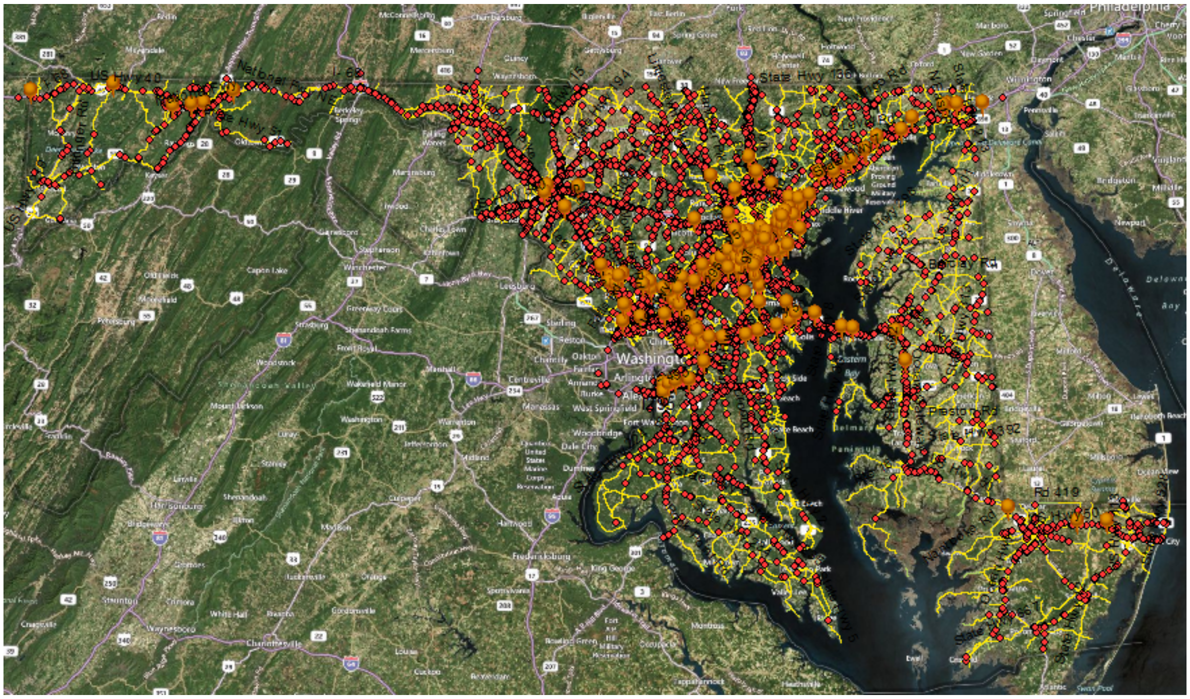


Figure 4.5. Map of accidents and DMS locations

4.2.4. AADT Database

Highway Safety Manual (2010) defines traffic flow as one of the most important contributing factors to occurrence of crashes. This research uses Average Annual Daily Traffic (AADT) of the road segments as an index for traffic flow. The AADT data are retrieved from Maryland's State Highway Administration volume maps for the four year period of study. The AADTs are collected from more than 3,000 Program Count Stations and 79 Automatic Traffic Recorders (ATRs) located throughout Maryland. The shape file of AADT layer is projected onto the road map along with the accidents and DMSs. An example of the map is shown in Figure 4.6.

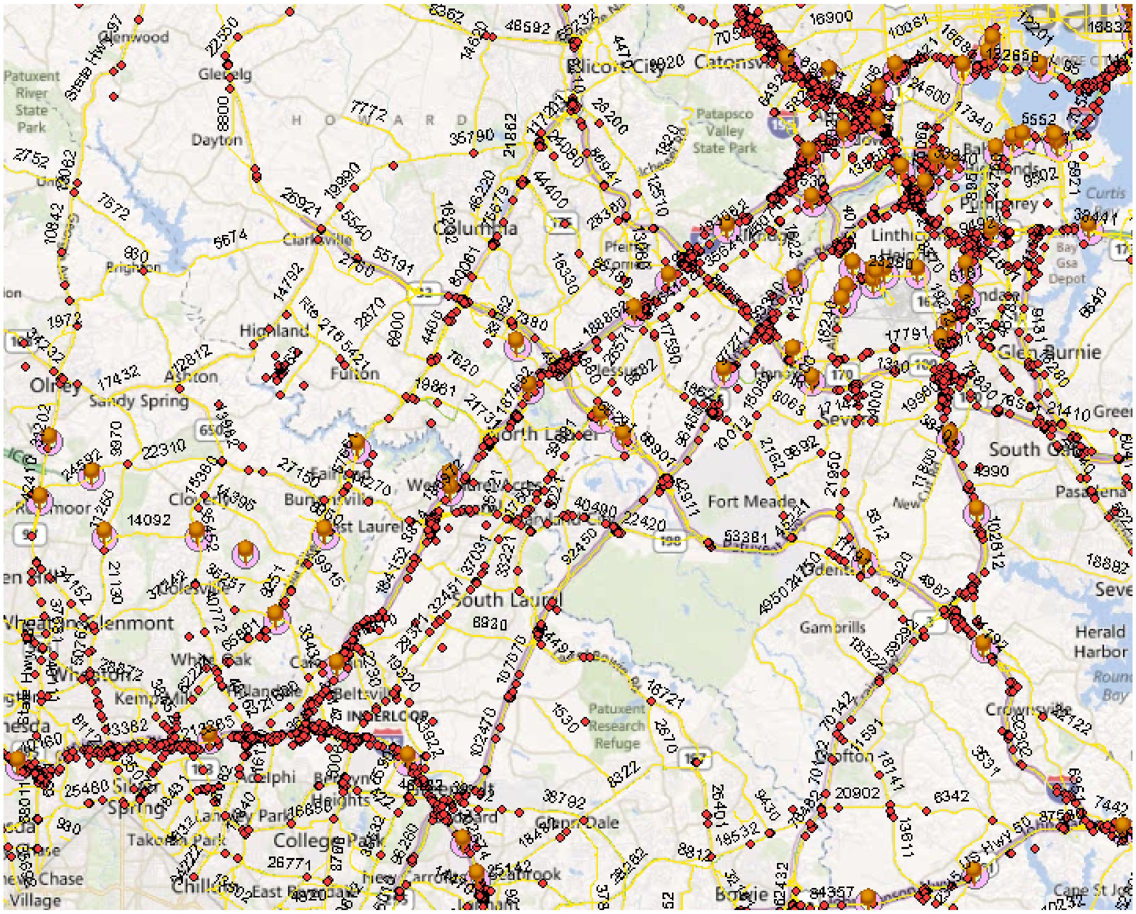


Figure 4.6. An example of the volume map AADT (SHA 2011)

4.3. Data Processing and Preparation Challenges

This study is a new approach to the problem dealing with several huge databases with different data structure and coordination systems. The need to acquire data from different sources was another challenge for the research. Besides, some parts of police accident report such as causes of the accidents are not accessible due to confidentiality concerns. Apart from the difficulties in obtaining the data, another issue confronting the research was processing of data sets with more than ten thousands of records that was resolved by the use of a data cleansing process with filtering and removing the outliers. The need to be joining the databases with two dimensions of time and location was another challenge that was resolved by pinpointing the locations through GIS tools and matching the time of events through coding in SQL environment.

4.4. Defining the Impact Area of DMS

The methodology used in this study is to pinpoint the locations of accidents to count the number of accidents within the 900 feet radius distance. When both the DMSs and accident locations are projected on ArcGIS, the goal was to determine the distance within which DMS might affect the occurrence of accidents. Size of characters of electronic signs is the important factor determining the maximum viewing distance. In order to define the distance within which DMS may affect occurrence of accidents, the visibility distance from DMS needs to be determined. According to Maryland Manual on Uniform Traffic Control Devices (MUTCD), the minimum character size of DMS fonts in major roads (55 mph speed limit) is 18 inches. Based on the information provided by International Sign Association the maximum viewing distance for 18 inches character size sign is 900 feet. Figure 4.7 illustrates the impact area for research.

4.5.Case Study on I-95

Interstate 95 in Maryland is a major highway that runs diagonally from northeast to southwest, from Maryland's border with Delaware, to the Woodrow Wilson Bridge, briefly entering the District of Columbia before reaching Virginia. The reason for choosing this freeway is that the route is one of the most heavily traveled Interstate Highways in Maryland, especially between Baltimore and Washington, D.C.

Figure 4.8 shows I-95 and the DMSs located on this highway. The light blue pushpins are DMSs on northbound and the dark one are the signs located on southbound.

Figure 4.7. Impact Area

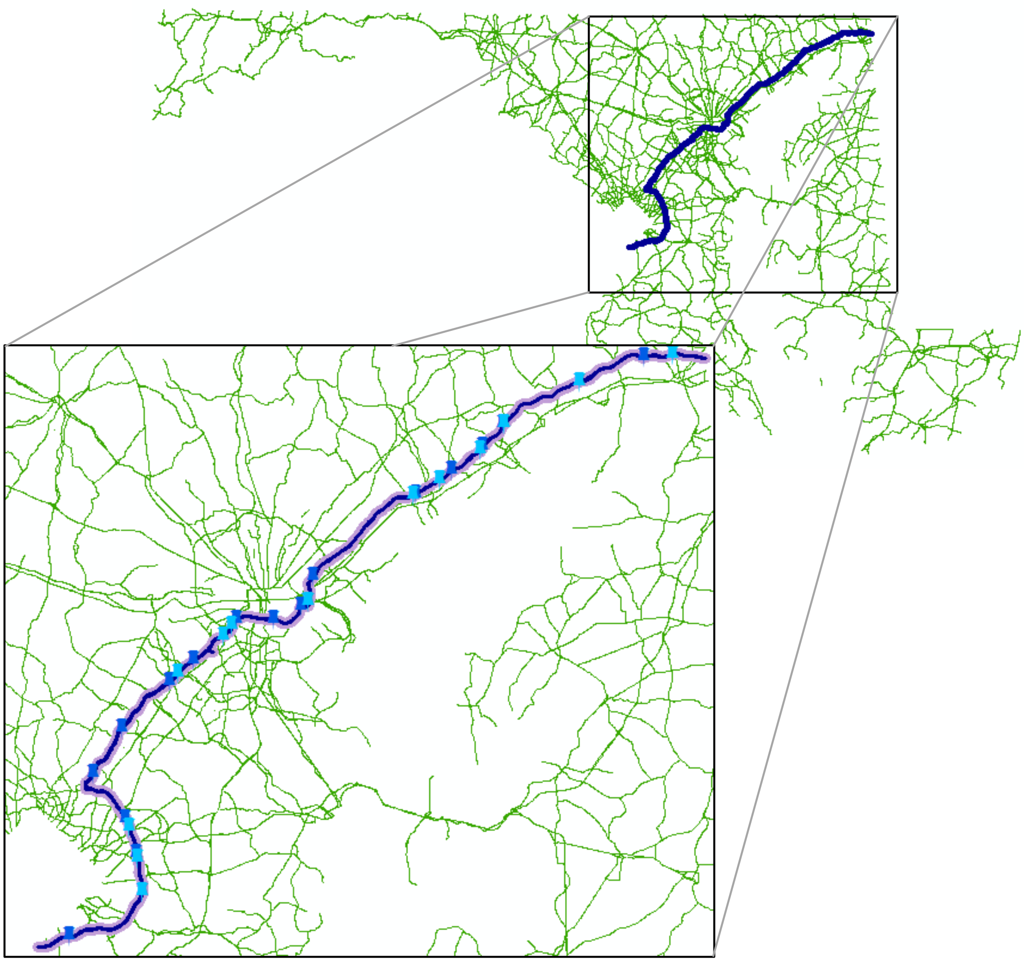


Figure 4.8. I-95 along with the DMSs along this highway

The accidents along I-95 are projected onto the map. Figure 4.9 gives a perspective of the accidents in I-95 and northbound and southbound DMSs.

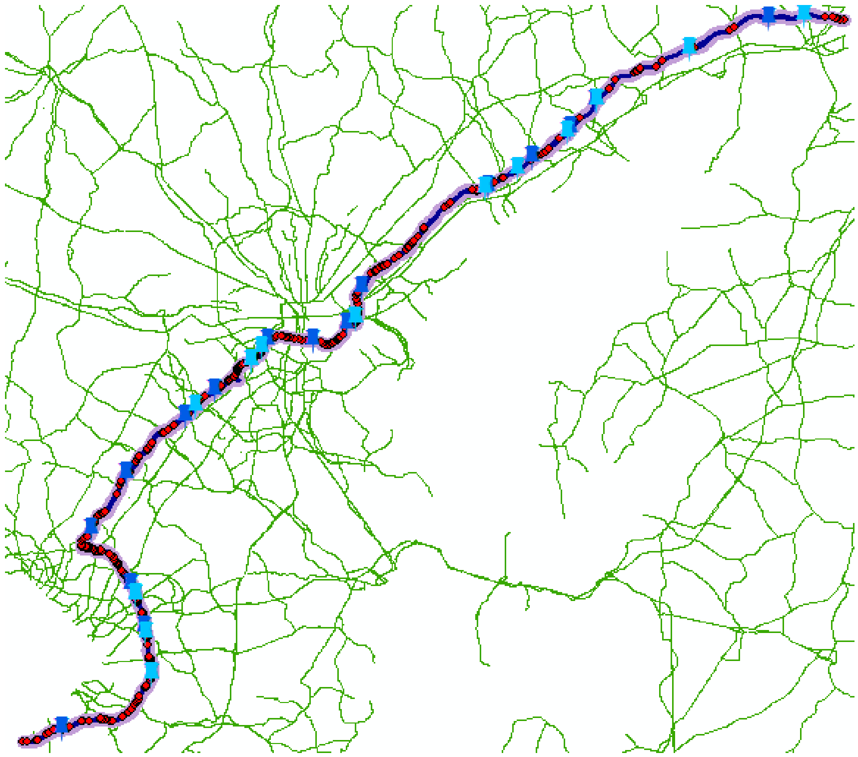


Figure 4.9. Accidents in I-95

Figure 4.10 shows the projected AADTs to road map.

Since the impact area of DMSs is determined as 900 feet, multiple ring buffer zones with radius of 900 multiplier feet (900, 1800, 2700, etc) radius were performed for each DMS sign along I-95. This is shown in Figure 4.11..

4.5.1. Analysis of Case Study and Preliminary Results

In this step, a sample of 70 geometrically homogenous segments with 900 feet length along I-95 highway is selected. . For each segment, accidents are counted and the accumulated number of crashes in each segment are tabulated and used for regression analysis considering that segment is an impact area or not as well as the existence of interchange and AADT in the segment. Table 4.1 shows the variable used for the case study.

Table 4.2 shows the 70 segments with their accumulated number of crashes, and existence of DMS and interchanges in the impact areas. To analyze the data, first an unbalanced two way ANOVA is performed using SAS software. The results show that P-value strongly rejects the hypothesis that Interchanges have no impact on the occurrence of accidents. The significance level for the impact of DMS is not high and shows that DMSs are not significantly contributing in occurrence of accidents. The results are shown in Figure 4.12.

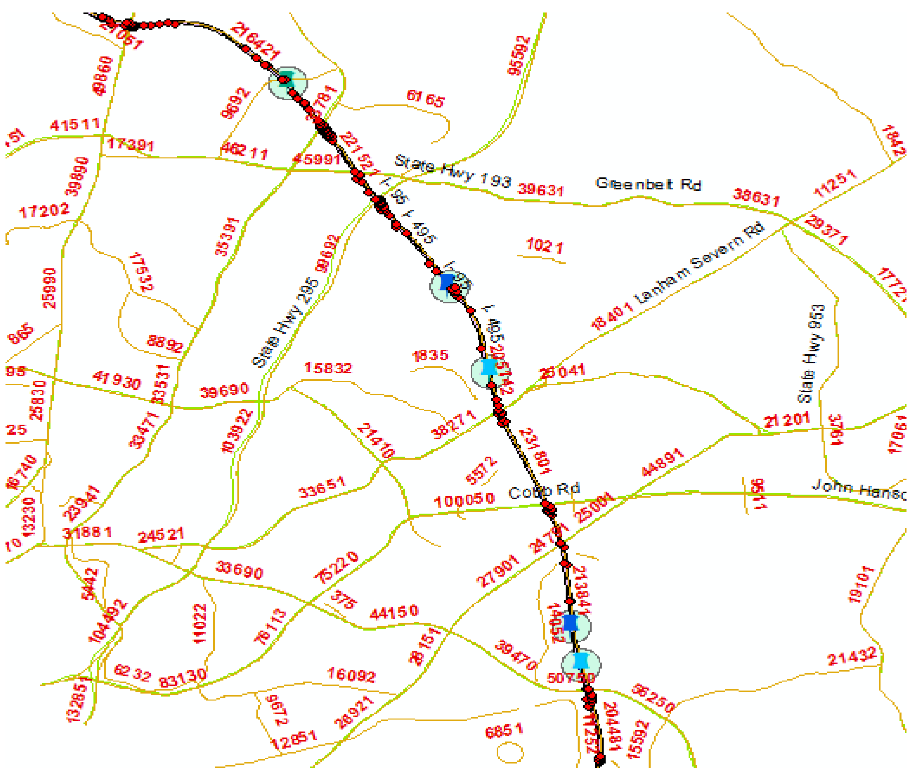


Figure 4.10 . Projection of AADTs to road map

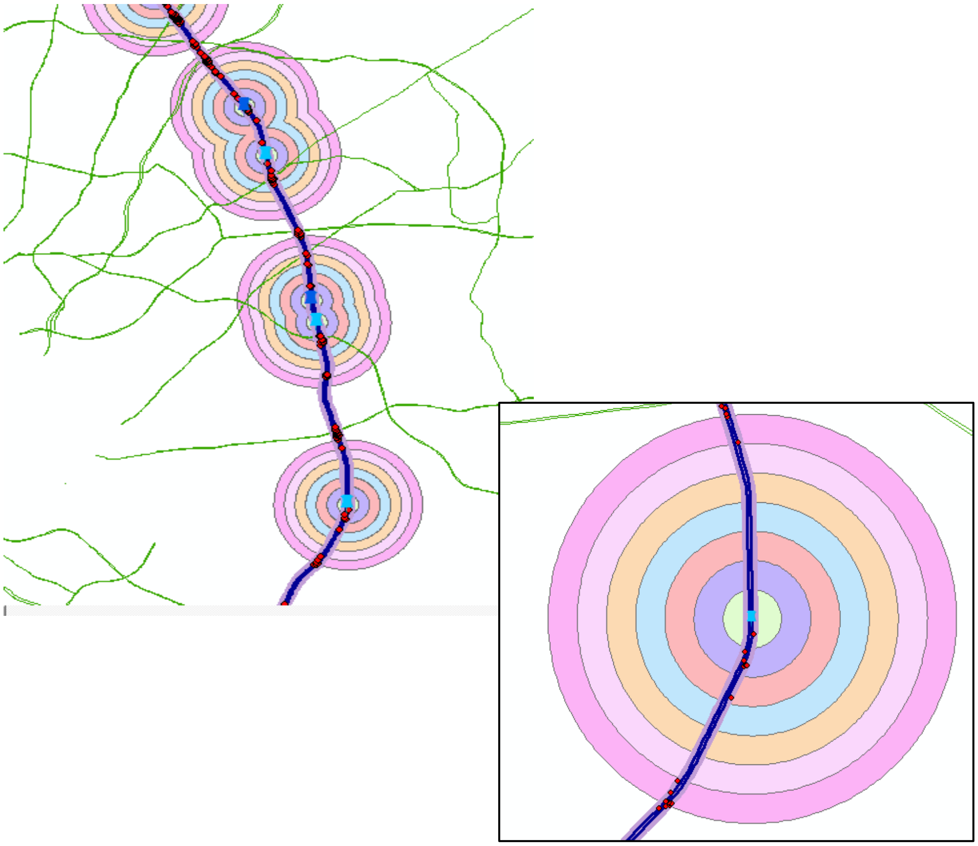


Figure 4.11. Multiple Buffers along I-95

Table 4.1. Variables used in case study

Dependent Variable	Independent Variables		
Number of crashes	Impact Area or not	Existence of Interchange	AADT

In addition, Poisson regression analysis is conducted to predict the number of crashes within 900 feet segments considering existence of DMSs, interchanges and AADT of the route. The test strongly rejects the hypothesis that interchanges and AADT do not have significant impact on the occurrence of accidents. Regression analysis also shows that DMSs are not significant contributors for crash occurrence. Figure 4.12 and Figure 4.13

show the outcome of ANOVA and Poisson regression analysis respectively. The results of both methods converge to the point that interchanges and AADT are important factors on accidents, but do not show any relationship between presence of DMSs and occurrence of accidents.

Table 4.2. I-95 Case Study Samples

BufferID	NumberCrash	ImpactArea	Interchange	AADTVMT	SouthORNorthBound
10	1	1	0	147581	S
20	1	1	0	147130	N
30	7	1	0	177981	S
40	1	1	0	206880	N
50	0	1	0	213841	N
60	0	1	0	213841	S
70	1	1	0	205142	N
80	28	1	0	205142	S
90	0	1	0	212261	N
100	0	1	0	188601	S
110	0	1	0	183961	S
120	3	1	0	188671	N
130	0	1	0	194069	N
140	0	1	0	192871	S
150	0	1	0	182473	N
160	40	1	0	182478	S
170	4	1	0	123232	S
180	0	1	0	129021	S
190	3	1	0	119161	N
200	2	1	0	165104	S
210	0	1	0	147341	N
220	1	1	0	147341	S
230	1	1	0	121581	N
240	0	1	0	121581	S
250	0	1	0	96951	N
260	0	1	0	96951	S
270	1	1	0	98941	N
280	2	1	0	98941	S
290	0	1	0	84721	N
300	0	1	0	91711	S
310	0	1	0	91711	N
320	43	0	1	191981	N
330	57	0	1	147581	S

340	2	0	1	147581	N
350	19	0	1	147130	N
360	10	0	1	213841	N
370	81	0	1	213841	S
380	8	0	1	231801	S
390	5	0	1	205142	N
400	15	0	1	221521	N
410	4	0	1	188671	N
420	15	0	1	182473	N
430	3	0	1	123232	N
440	16	0	1	147341	N
450	9	0	1	98941	N
460	5	0	1	80571	N
640	3	1	1	187501	N
650	38	1	1	174051	S
960	18	0	0	147130	S
970	1	0	0	177981	N
980	9	0	0	177981	S
990	1	0	0	177981	N
1000	1	0	0	213841	N
1010	1	0	0	213841	S
1020	1	0	0	205142	S
1030	2	0	0	205142	S
1040	2	0	0	212261	N
1050	2	0	0	183961	N
1060	0	0	0	194069	S
1070	11	0	0	192871	N
1080	1	0	0	192871	N
1090	4	0	0	175027	N
1100	9	0	0	129021	N
1110	17	0	0	129021	S
1120	5	0	0	119151	N
1130	0	0	0	165104	S
1140	1	0	0	161521	S
1150	1	0	0	96951	S
1160	0	0	0	9651	N
1170	0	0	0	98841	N

Dependent Variable: NumberCrash NumberCrash

Source	DF	Sum of Squares	Mean Square	F Value
Model	2	3356.89535	1678.44767	10.43
Error	67	10781.44751	160.91713	
Corrected Total	69	14138.34286		

Source	Pr > F
Model	0.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	NumberCrash Mean
0.237432	172.0876	12.68531	7.371429

Source	DF	Type I SS	Mean Square	F Value
ImpactArea	1	647.289622	647.289622	4.02
Interchange	1	2709.605723	2709.605723	16.84

Source	Pr > F
ImpactArea	0.0489
Interchange	0.0001

Figure 4.12. SAS outcomes of unbalanced two-way ANOVA for case study in I-95

Recent studies in the literature raised some concerns regarding the usage of a Poisson distribution for accident frequency regression models. They state that one characteristic of crash-frequency data could be the probability that the variance exceeds the mean of the crash counts (Dominique et al, 2010) and since a property of Poisson distribution is that the mean and variance are equal, this could be problematic. To ensure verification of results, a Negative Binomial regression was also performed. The results of Negative Binomial regression also converges Poisson regression. P-value of 0.0006 strongly rejects the hypothesis that interchanges are not significant contributors but P-value of 0.34 suggests that DMSs are not contributing factors to occurrence of accidents. The result for Negative Binomial regression analysis agrees with the Poisson regression analysis in favor of the fact that DMSs do not affect causing accidents. The coding and outcomes are presented in Figure 4.13 and Figure 4.14.

Model Information

Data Set	WORK.AUTO1	
Distribution	Negative Binomial	
Link Function	Log	
Dependent Variable	NumberCrash	NumberCrash

Number of Observations Read	70
Number of Observations Used	70

Class Level Information

Class	Levels	Values
ImpactArea	2	0 1
Interchange	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	66	74.7226	1.1322
Scaled Deviance	66	74.7226	1.1322
Pearson Chi-Square	66	105.3643	1.5964
Scaled Pearson X2	66	105.3643	1.5964
Log Likelihood		993.4624	

Algorithm converged.

Figure 4.13. SAS outcomes of Poisson regression for case study in I-95

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square
Intercept		1	0.8597	1.0341	-1.1672	2.8865	0.69
AADTVMT		1	0.0000	0.0000	0.0000	0.0000	4.17
ImpactArea	0	1	0.3691	0.3878	-0.3909	1.1290	0.91
ImpactArea	1	0	0.0000	0.0000	0.0000	0.0000	.

Analysis Of Parameter Estimates

Parameter		Pr > ChiSq
Intercept		0.4058
AADTVMT		0.0412
ImpactArea	0	0.3412
ImpactArea	1	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square
Interchange	0	1	-1.4819	0.4315	-2.3276	-0.6361	11.79
Interchange	1	0	0.0000	0.0000	0.0000	0.0000	.
Dispersion		1	1.9123	0.3831	1.1613	2.6632	

Analysis Of Parameter Estimates

Parameter		Pr > ChiSq
Interchange	0	0.0006
Interchange	1	.
Dispersion		

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.

Figure 4.13 (Continued). SAS outcomes of Poisson regression for case study in I-95

Model Information

Data Set	WORK.AUTO1	
Distribution	Negative Binomial	
Link Function	Log	
Dependent Variable	NumberCrash	NumberCrash

Number of Observations Read	70
Number of Observations Used	70

Class Level Information

Class	Levels	Values
ImpactArea	2	0 1
Interchange	2	0 1

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	66	74.7226	1.1322
Scaled Deviance	66	74.7226	1.1322
Pearson Chi-Square	66	105.3643	1.5964
Scaled Pearson X2	66	105.3643	1.5964
Log Likelihood		993.4624	

lgorithm converged.

Figure 4.14. SAS outcomes of Negative Binomial regression for case study in I-95

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square
Intercept		1	0.8597	1.0341	-1.1672	2.8865	0.69
AADTVMT		1	0.0000	0.0000	0.0000	0.0000	4.17
ImpactArea	0	1	0.3691	0.3878	-0.3909	1.1290	0.91
ImpactArea	1	0	0.0000	0.0000	0.0000	0.0000	.

Analysis Of Parameter Estimates

Parameter		Pr > ChiSq
Intercept		0.4058
AADTVMT		0.0412
ImpactArea	0	0.3412
ImpactArea	1	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square
Interchange	0	1	-1.4819	0.4315	-2.3276	-0.6361	11.79
Interchange	1	0	0.0000	0.0000	0.0000	0.0000	.
Dispersion		1	1.9123	0.3831	1.1613	2.6632	

Analysis Of Parameter Estimates

Parameter		Pr > ChiSq
Interchange	0	0.0006
Interchange	1	.
Dispersion		

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.

Figure 4.14 (Continued). SAS outcomes of Negative Binomial regression for case study in I-95

4.6. Weather Conditions Database

An important factor in causing driver distraction is visibility while driver tries to read the messages. Since precipitation, wind gust and severe weather conditions could have adverse impact on visibility of messages, another factor that contributes in occurrence of accidents and should be accounted for is climate status. The factors that are analyzed for weather conditions include precipitation, gust and visibility factors. The weather data for this research are retrieved from DOT archived databases. The initial format of the database was in the shape of month to month archived data collected from 49 weather tower stations and contained the following data fields: date and time, air temperature, humidity, average wind speed, wind gust, wind direction, precipitation type, precipitation intensity (light, medium, heavy), precipitation accumulation, rate (rate per hour in inches), visibility (miles) and surface temperature.

For simplicity, the area of research is divided into 5 regions of north, south, west, east and Washington, DC. The nearest central weather tower station in each region is assigned to represent the weather condition in that region. Table 4.3 shows these regions.

Table 4.3. Tower stations assigned to each weather region

Weather Station	Region	Latitude	Longitude
I-68 @ Cumberland	West	39.70302	-78.63177
US 50 Kent Narrow Bridge	East	38.97203	-76.25391
I-895 @ Levering Ave	North	39.21854	-76.71071
US-301 at Potomac River	South	38.36366	-76.983
I-270 @ I-370	Washington, DC	39.11946	-77.19593

The data set is accumulated for the four-year period of study (2007-2010). Figure 4.15 shows the format of weather database. As mentioned earlier, if an accident in the database lies within 900 feet sight distance of an onward DMS, the accident is joined with that DMS and AADT of the roadway on which that accident has occurred. In this step, the main database is integrated with the weather stations data sets. The weather database is joined to the main database based on proximity to the closest weather tower station and occurrence time of accident.

For integrating the weather database and the main database, the weather database was imported into SQL server and each accident was matched with the closest weather tower station and the weather condition at the time of accident. The matching process is performed using SQL queries coded in C++.

1	Date / Time reported (GMT)	Air Temperature	Relative Humidity	Dew Point Temperature	Average Wind Speed	Wind Gust	Wind Direction	Precipitation Type	Precipitation Intensity	Rate	Visibility	Surface Tepmerature
328528	1/1/2007 3:26	44	99	44	0	3	NW	None	None	0		44 - 45
328529	1/1/2007 3:24	44	99	44	0	2	N	None	None	0		44 - 45
328530	1/1/2007 3:13	44	99	44	0	2	W	Rain	Slight	0		44 - 45
328531	1/1/2007 3:03	44	99	44	0	0	W	None	None	0		44 - 45
328532	1/1/2007 3:01	44	99	44	0	0	W	None	None	0		44 - 45
328533	1/1/2007 2:50	44	99	44	0	2	W	None	None	0		44 - 45
328534	1/1/2007 2:44	44	99	44	0	2	N	None	None	0		44 - 45
328535	1/1/2007 2:40	44	99	44	0	2	NE	Rain	Slight	0		44 - 45
328536	1/1/2007 2:30	44	99	44	0	0	NW	Rain	Slight	0		44 - 45
328537	1/1/2007 2:24	44	99	44	0	2	W	Rain	Slight	0.1		44 - 45
328538	1/1/2007 2:20	44	99	44	0	2	N	Rain	Slight	0		44 - 45
328539	1/1/2007 2:08	44	99	44	0	0	W	Rain	Slight	0		44 - 45
328540	1/1/2007 2:03	44	99	44	0	1	NW	Rain	Slight	0.1		44 - 45
328541	1/1/2007 1:57	44	99	44	0	1	NW	Rain	Slight	0.1		44 - 45
328542	1/1/2007 1:46	44	99	44	2	4	NW	Rain	Slight	0.1		44 - 45
328543	1/1/2007 1:43	44	99	44	1	3	NW	Rain	Slight	0		44 - 45
328544	1/1/2007 1:35	44	99	44	1	3	NW	Rain	Slight	0		44 - 45
328545	1/1/2007 1:25	44	99	44	0	1	W	Rain	Slight	0		44 - 45
328546	1/1/2007 1:23	44	99	44	0	0	W	Rain	Slight	0		44 - 45
328547	1/1/2007 1:12	44	99	44	0	0	NW	Rain	Slight	0		44 - 45
328548	1/1/2007 1:04	44	99	44	0	1	SE	Rain	Moderate	0.2		44 - 45
328549	1/1/2007 1:02	44	99	44	0	2	SE	Rain	Slight	0.1		44 - 45
328550	1/1/2007 0:51	44	99	44	1	2	SE	Rain	Moderate	0.1		44 - 45
328551	1/1/2007 0:43	44	99	44	0	2	E	Rain	Slight	0		44 - 45

Figure 4.15. Weather Database Format

4.7. Log of Messages Database

The database for log of messages as mentioned before was acquired from the CATT Laboratory in the Department of Civil and Environmental Engineering at the University of Maryland, College Park. This database contains whole messages displayed on all of the DMSs in State of Maryland during the time period of 2007 to 2010. This database is a huge data sheet which includes 1,047,586 records of messages and consists of identification number of DMSs, time of displaying the messages, the messages and beacon data fields. The beacon data field shows that if the beacon has been on or off. Figure 4.16 show the log of messages database.

The syntax for message data field is based on the definitions in National Transportation Communications for ITS Protocol, Object Definitions for Dynamic Message Signs Version 02 (2007). The number of panes can be determined by interpreting the system of coding that comes along with each message. The main codes of messages are:

- [PT##O#]: This code is interpreted as Panel Time, ## in tenths of seconds on, # in tenths of seconds off (normally this # is 0, otherwise the panel would be flashing)
- [JL#]: This code is for text justification. The number corresponds to various justifications (i.e. 2 left, 3 center, 4 right)
- [NL] - New Line
- [NP] - New Pane

1	dms_id	start_tstamp	message	beacon
109	CHART_010004f800fc00bf003e832c33235daa	12/24/2008 15:15	[PT25O0][JL3]I-95 TUNNEL[NL][JL3]MAJOR DELAYS[NL][JL3]STAY ALERT	on
110	CHART_010004f800fc00bf003e832c33235daa	12/24/2008 15:20	[PT25O0][JL3]I-95 TUNNEL[NL][JL3]MAJOR DELAYS[NL][JL3]STAY ALERT	on
111	CHART_010004f800fc00bf003e832c33235daa	12/24/2008 15:24	[PT25O0][JL3]I-95 TUNNEL[NL][JL3]MAJOR DELAYS[NL][JL3]STAY ALERT	on
112	CHART_010004f800fc00bf003e832c33235daa	12/24/2008 17:51	[PT25O0][JL3]I-95 TUNNEL[NL][JL3]MAJOR DELAYS[NL][JL3]STAY ALERT	on
113	CHART_010004f800fc00bf003e832c33235daa	12/24/2008 17:52	[PT25O0][JL3]I-95 TUNNEL[NL][JL3]MAJOR DELAYS[NL][JL3]STAY ALERT	on
114	CHART_010004f800fc00bf003e832c33235daa	12/24/2008 23:51		off
115	CHART_010004f800fc00bf003e832c33235daa	12/24/2008 23:55		off
116	CHART_010004f800fc00bf003e832c33235daa	12/25/2008 0:52	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
117	CHART_010004f800fc00bf003e832c33235daa	12/25/2008 6:56	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
118	CHART_010004f800fc00bf003e832c33235daa	12/25/2008 7:00	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
119	CHART_010004f800fc00bf003e832c33235daa	12/25/2008 8:31	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
120	CHART_010004f800fc00bf003e832c33235daa	12/25/2008 8:35	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
121	CHART_010004f800fc00bf003e832c33235daa	12/25/2008 14:04	[PT25O0][JL3]ACCIDENT AHEAD[NL][JL3]PAST EXIT 51[NL][JL3]2 LEFT LANES BLOCKEI	on
122	CHART_010004f800fc00bf003e832c33235daa	12/25/2008 14:39	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
123	CHART_010004f800fc00bf003e832c33235daa	12/26/2008 8:17	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
124	CHART_010004f800fc00bf003e832c33235daa	12/26/2008 8:21	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
125	CHART_010004f800fc00bf003e832c33235daa	12/26/2008 12:48	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT[NP]	off
126	CHART_010004f800fc00bf003e832c33235daa	12/26/2008 13:06	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
127	CHART_010004f800fc00bf003e832c33235daa	12/26/2008 15:16	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
128	CHART_010004f800fc00bf003e832c33235daa	12/26/2008 15:20	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
129	CHART_010004f800fc00bf003e832c33235daa	12/27/2008 1:41	[PT25O0][JL3]DISABLED VEHICLE[NL][JL3]PAST EXIT 55[NL][JL3]RIGHT LANE BLOCKED	off
130	CHART_010004f800fc00bf003e832c33235daa	12/27/2008 1:45	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
131	CHART_010004f800fc00bf003e832c33235daa	12/27/2008 6:31	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off
132	CHART_010004f800fc00bf003e832c33235daa	12/27/2008 6:35	[PT25O0][JL3]ROADWORK [NL][JL3]AT TUNNEL TOLL PLAZA[NL][JL3]STAY ALERT	off

Figure 4.16. Log of Messages Database

The following example illustrates the message syntax:

[PT25O0][JL3]ACCIDENT AHEAD[NL][JL3][NL][JL3]PAST EXIT 51[NP][PT25O0][JL3] 2 LEFT LANES BLOCKED[NL][JL3][NL][JL3] EXPECT DELAYS

This message has 2 panes, alternating appearances for 2.5 seconds, all lines center justified. It would appear as:

PANE 1:
ACCIDENT AHEAD

PAST EXIT 51

PANE 2:
2 LEFT LANES BLOCKED

EXPECT DELAYS

The message log database is imported into SQL server along with the main database. For each accident if it was located in impact area, the assigned DMS is matched with the message displayed at the occurrence time of accident. Likewise the weather data sets, the matching process was conducted using SQL queries coded in C++.

4.8. Analysis and Results

The integrated database consists of the integrated data for each accident. Every record of an accident contains the following information: time and date of accident, location and longitude and latitude of accident, type of accident, AADT of the roadway, weather condition at the time of accident (including air temperature, humidity, average wind speed, wind gust, wind direction, precipitation type and rate and visibility). If the accident occurred in the impact area, the following information are also present: the assigned DMS and the message that DMS had displayed at the time of accident.

Figure 4.17 depicts the projection of integrated database for the entire study area in ArcGIS.

Figure 4.18 illustrates the close up shot of the projected map.

The integrated database consists of 23,842 records for accident during the time period of 2007 to 2010. There are 298 accidents located in 900 feet vicinity of DMSs. From whole accidents in impact areas, there are 50 accidents exposed to the active DMSs with displaying messages. For the rest of accidents, the DMSs were inactive at the time of accidents. As the following sections present, multiple approaches are employed to analyze different aspects of the data. A paired t-test analysis at 95% significant level is conducted to compare accident rate in impact areas with their onward 900 feet segment. In addition, an on-and-off study is conducted to compare accident rates of 15 DMSs with on and off displaying messages. Statistical analyses to investigate the effects of weather conditions, visibility and type of messages on accident in impact areas are presented in the subsequent sections.

4.9. Analysis on Impact Areas and Following Segment

To investigate the effects of DMSs on occurrence of road accidents, a paired t-tests statistical analysis at 95% confidence level is used to compare accident rates for the 50 accidents in impact areas of active DMSs with displaying messages with their subsequent 900 feet segment.

The null hypothesis states that the difference in mean accident rate between two consecutive 900 feet segments is equal to zero. On the other hand, the alternative hypothesis suggests that difference between the means is not equal to zero:

$$H_0 : \mu_2 - \mu_1 = 0$$
$$H_1 : \mu_2 - \mu_1 \neq 0$$

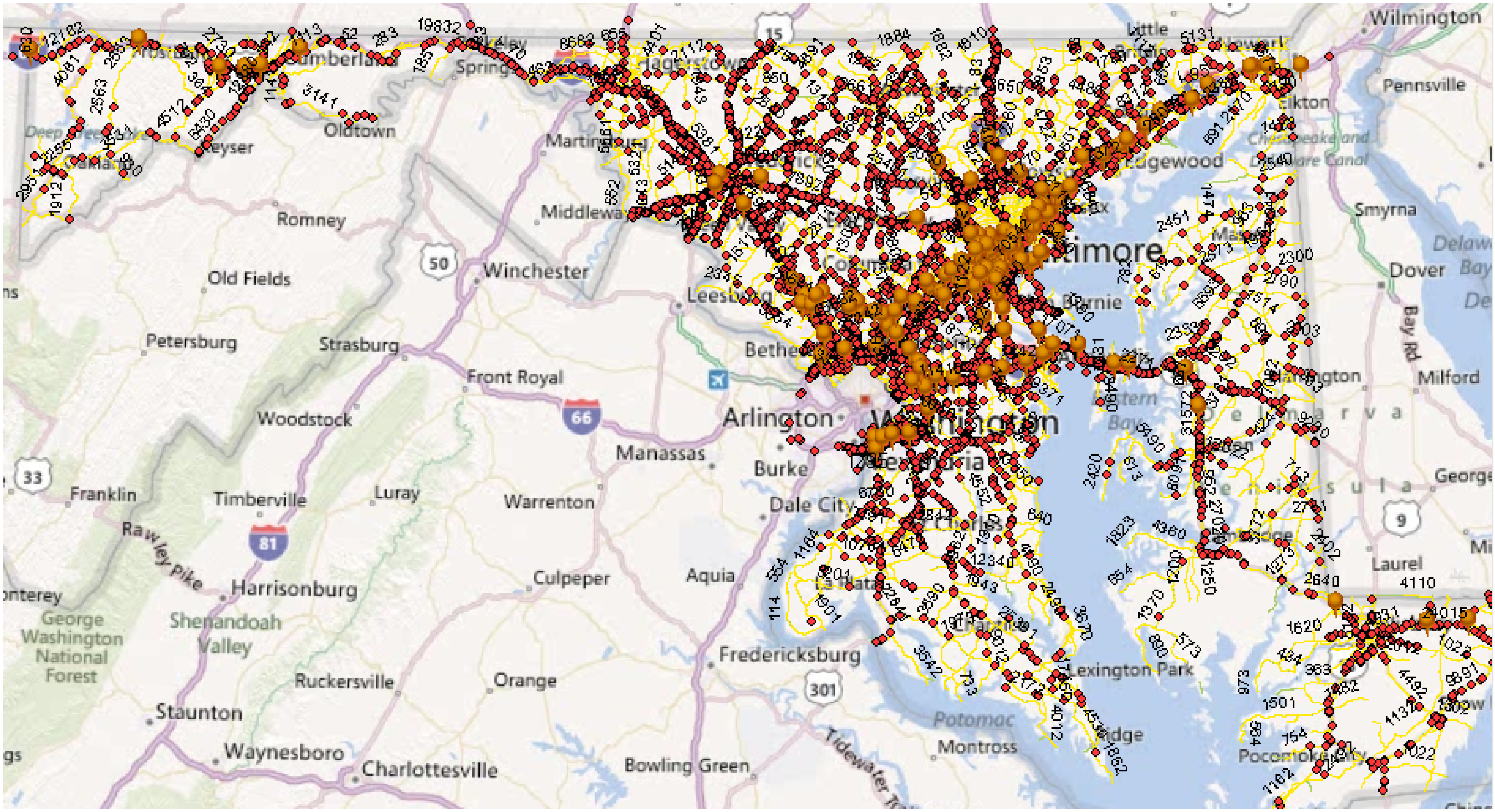


Figure 4.17. Projection of Integrated Database

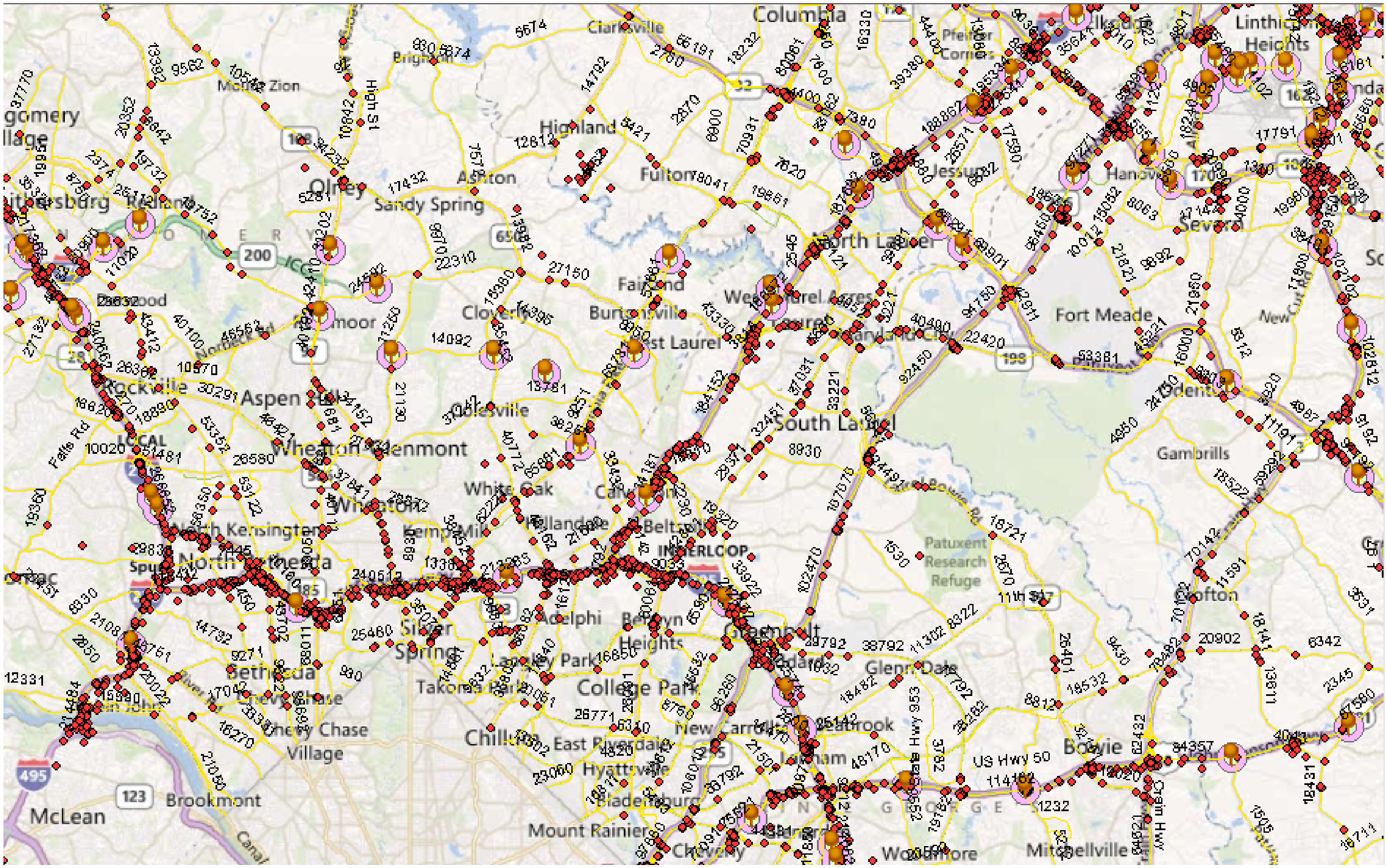


Figure 4.18. Close up shot of projected map

The data was compiled and the total number of accidents in each impact area and its subsequent 900 feet along with AADT of the segment were tabulated. The accident rates for both segments were calculated using spot accident rate formulation recommended by FHWA Safety Program guidance and Kiewit Center at Oregon State University (2003). According to the formulation, accident rate for a spot of a road is calculated by a ratio of accidents per million vehicles. A spot location is generally defined as a location about 0.3 miles or less in length. Since the segments compared in this study are 900 feet length, equal to 0.17 mile, this formulation is used to calculate the accident rate. The normalized formula would allow comparing various accidents rates with respect to the rates of the subsequent segments. The equation for computing accident rate for a spot location is as follows:

Rsp = A/Exposure [million entering vehicles] (Equation 1)

or

Rsp = (C) (1,000,000)/AADT (365)(N)

Where:

Rsp = Accident rate at a spot in accidents per million vehicles,

C = Number of crashes for the study period,

N = Period of study (years or fraction of years),

AADT = Average Annual Daily Traffic (AADT) during the study period.

For this formulation of accident rates, a segment of less than 0.3 miles would not be appropriate to be treated as a section and should be considered a spot rather than a segment. (Kiewit 2003)

Table 4.4 shows the tabulated facts for the accident rates in both segments compiled in a table including DMS identification number, AADT of segment, number of accidents in segment and accident rates in segments. Figure 4.19 shows the accident rates for impact areas compared to their subsequent 900 feet segment.

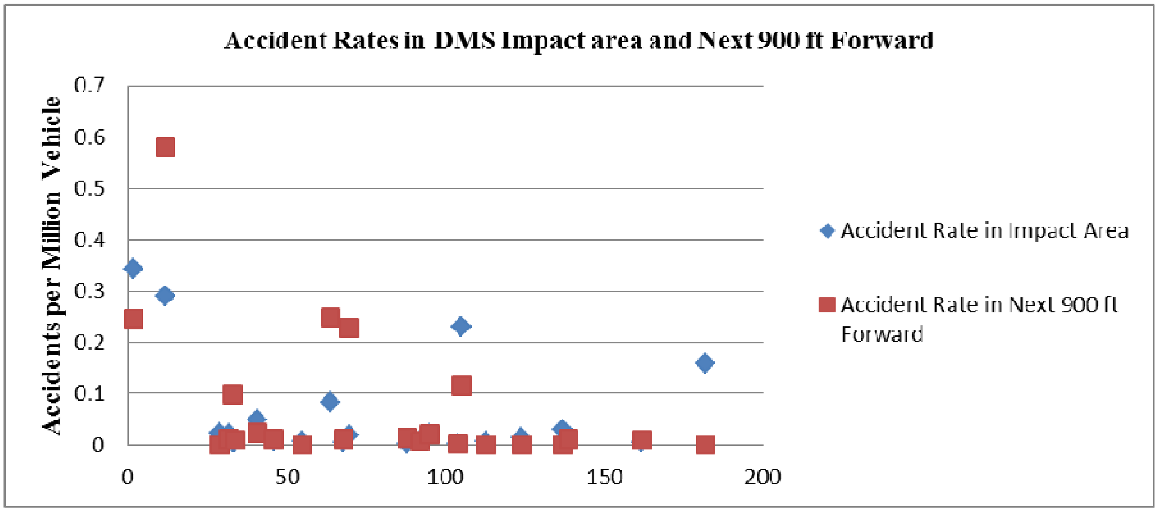


Figure 4.19. Accident rate for impact area of 900 feet compared to their subsequent900 feet segment

The graph shows that for the majority of impact areas, rate of accidents is lower than their onward adjacent segment. Figure 4.20 shows the difference of the accidents rates for the two segments,

Table 4.4. Tabulated facts of impact areas and forwarding segments

Impact Area	DMS_id	AADT	# accidents in 900 feet	900ft Accident Rate	# accidents in Forward 900 feet	Forward 900ft Accident Rate	DMS
2	CHART_01010528004f00820047f02c76235daa	13974	7	0.343102945	5	0.245073532	0.098029
12	CHART_0c011090002d0067003f062c3d235daa	2364	1	0.28973414	2	0.57946828	-0.28973
29	CHART_190117090005000200３d242c3b235daa	61273	2	0.022356715	0	0	0.022357
32	CHART_1b010c38005200820047f02c76235daa	65821	2	0.020811945	1	0.010405972	0.010406
33	CHART_1b01212600da0008003d242c3b235daa	187920	1	0.003644804	27	0.098409699	-0.09476
34	CHART_1c000b26004c00820047e22c9e235daa	145780	1	0.004698391	2	0.009396783	-0.0047
41	CHART_1e01133800d90008003d242c3b235daa	57512	4	0.047637467	2	0.023818734	0.023819
46	CHART_2c00083a004b00820047e22c9e235daa	444336	5	0.00770736	7	0.010790304	-0.00308
55	CHART_39010a59005100820047f02c76235daa	88882	1	0.007706077	0	0	0.007706
64	CHART_40ff12d400c200820047e32c96235daa	8282	1	0.08270122	3	0.248103661	-0.1654
68	CHART_46010ade0036005a0039fc442f1f5daa	190391	1	0.003597499	3	0.010792498	-0.00719
70	CHART_4701165e00d90008003d242c3b235daa	74887	2	0.018292401	25	0.228655009	-0.21036
88	CHART_5f00077a004600820047e32c96235daa	245421	1	0.002790843	5	0.013954216	-0.01116
92	CHART_62000ff900a300e0003e062c3d235daa	121581	1	0.005633541	1	0.005633541	0
95	CHART_650113d6003d0067003f062c3d235daa	65214	2	0.021005659	2	0.021005659	0
104	CHART_6dff058b004500820047e32c96235daa	255882	1	0.002676748	1	0.002676748	0
105	CHART_6e00069600af0054003afc442f1f5daa	23726	8	0.230947149	4	0.115473574	0.115474
113	CHART_74000733009000d3003e062c3d235daa	98941	1	0.006922626	0	0	0.006923
124	CHART_89000cab00d80008003d242c3b235daa	147130	3	0.013965843	0	0	0.013966
137	CHART_aa01033e000c00630045152cea235d0a	23741	1	0.028850154	0	0	0.02885
139	CHART_ac0064d1002f00ae003ac7442f1f5daa	66761	1	0.010259455	1	0.010259455	0
162	CHART_d8ff030400b800c60047832c33235daa	153481	1	0.004462647	2	0.008925294	-0.00446
182	CHART_fdff03d9008000c80040062c3d235daa	8600	2	0.159286397	0	0	0.159286
			50				

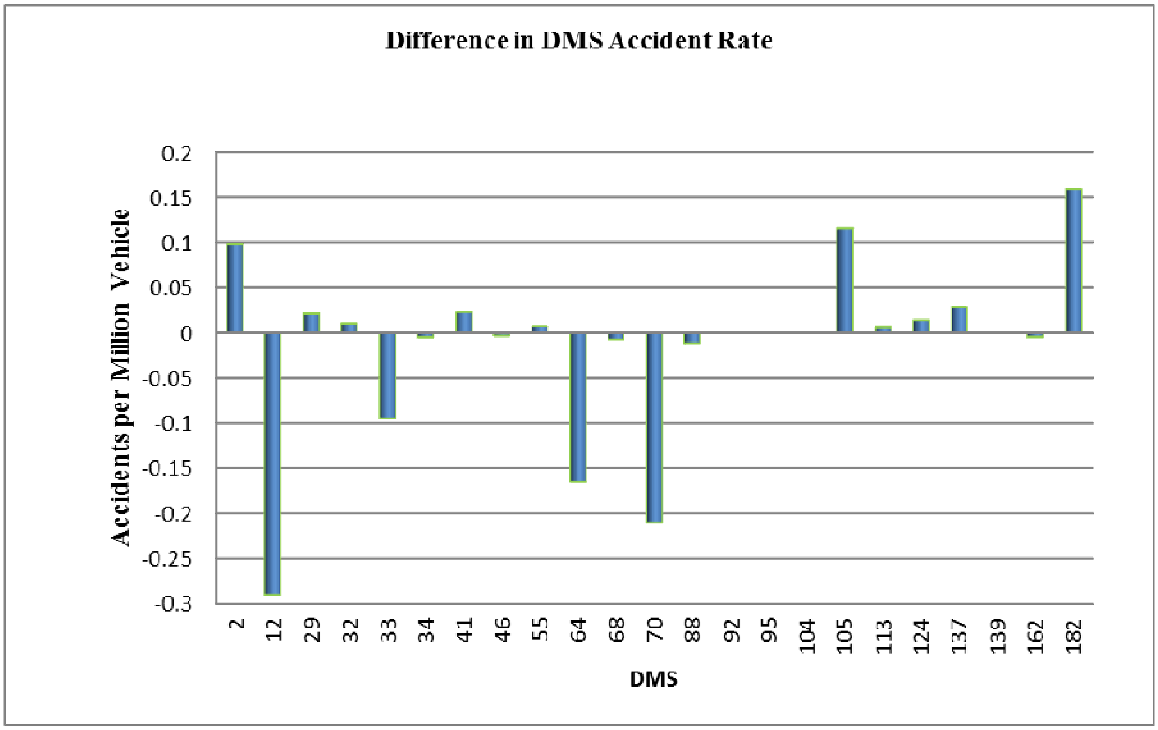


Figure 4.20. Difference of the accidents rates between the impact area and its subsequent segment

The analysis of difference between the accident rates show that 70% of the impact areas has lower or equal accident rates compared to their subsequent 900 feet segments which means DMSs do not have significant influence on increasing the accident rate. The remaining 30%, or 7 impact areas of the study, show a positive difference between the accident rates. As the results of the case study in I-95 supported the fact that interchanges are contributing factor to accidents, a simple qualitative analysis of the locations of the DMS with the highest accidents rates showed that they tended to occur within short distances of interchanges and those with lower rates tended to occur further away from interchanges, so the reason for positive accident rates could be attributed to external factors such as existence of interchanges in DMS buffer zones and roadway geometry that would increase the accident rates in these segments.

4.9.1. Findings

A paired t-test statistical analysis on the accident rates is performed to compare the accident rates in the two segments. The p-value of 0.5245 associated with t statistic of -0.65 suggest that DMSs do not increase occurrence of the accidents. The mean difference of the two accident rates is -0.013. The coding in SAS software and the results are presented in Figure 4.21.

Obs	Impact Area	DMS
1	2	0.09803
2	12	-0.28973
3	29	0.02236
4	32	0.01041
5	33	-0.09476
6	34	-0.00470
7	41	0.02382
8	46	-0.00308
9	55	0.00771
10	64	-0.16540
11	68	-0.00719
12	70	-0.21036
13	88	-0.01116
14	92	0.00000
15	95	0.00000
16	104	0.00000
17	105	0.11547
18	113	0.00692
19	124	0.01397
20	137	0.02885
21	139	0.00000
22	162	-0.00446
23	182	0.15929

Figure 4.21. SAS outcomes for comparison of impact areas and following section

The TTEST Procedure

Statistics

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev
DMS	23	-0.056	-0.013	0.0292	0.0758	0.098

Statistics

Variable	Upper CL Std Dev	Std Err	Minimum	Maximum
DMS	0.1387	0.0204	-0.29	0.1593

T-Tests

Variable	DF	t Value	Pr > |t|
DMS	22	-0.65	0.5245

Figure 4.21 (Continued). SAS outcomes for comparison of impact areas and following section

4.10. On-and-off Analysis

An on-and-off study was conducted to compare the results obtained from the previous section. The data were compiled into a table. Total numbers of accidents for 15 signs were accumulated while DMSs were displaying messages and when they were blank. The accident rates for both situations were calculated using the same formulation used for the previous section. To conduct the analysis, a one-way ANOVA with pairwise comparison test was performed to assess accident rates in impact area while DMSs were on and when they were off. The null hypothesis states that the difference in mean accident rate between two conditions is equal to zero. On the other side, the alternative hypothesis suggests that the difference between the means is not equal to zero and mean accident rate is different with or without presence of messages. Table 4.5 shows the tabulated facts of on-and-off study including DMS identification number, number of accidents in impact areas, AADT of segment and accident rates in segments.

Figure 4.22 depicts the comparison of accident rates when messages are displaying on DMSs and when these signs are blank.

To better determine how different the accidents rates are for on and off DMSs, the graph of the difference between the rates of the two conditions is shown in Figure 4.23. As this graph shows, in all DMS impact areas the accident rate is lower when the sign shows a message.

Table 4.5. Tabulated facts of on and off study

Impact Area	DMS_id	# accidents in impact area	With DMS Message Accident Rate	AADT	DMS blank before	DMS Blank Accident Rate	DMS Effect
2	CHART_01010528004f00820047f02c76235daa	7	0.343102945	13974	11	0.53916177	-0.196059
29	CHART_19011709000050002003d242c3b235daa	2	0.022356715	61273	7	0.078248503	-0.055892
32	CHART_1b010c38005200820047f02c76235daa	2	0.020811945	65821	8	0.083247779	-0.062436
33	CHART_1b01212600da0008003d242c3b235daa	1	0.003644804	187920	4	0.014579215	-0.010934
34	CHART_1c000b26004c00820047e22c9e235daa	1	0.004698391	145780	1	0.004698391	0
41	CHART_1e01133800d90008003d242c3b235daa	4	0.047637467	57512	19	0.22627797	-0.178641
46	CHART_2c00083a004b00820047e22c9e235daa	5	0.00770736	444336	16	0.024663552	-0.016956
55	CHART_39010a59005100820047f02c76235daa	1	0.007706077	88882	1	0.007706077	0
64	CHART_40ff12d400c200820047e32c96235daa	1	0.08270122	8282	6	0.496207322	-0.413506
68	CHART_46010ade0036005a0039fc442f1f5daa	1	0.003597499	190391	2	0.007194999	-0.003597
70	CHART_4701165e00d90008003d242c3b235daa	2	0.018292401	74887	7	0.064023403	-0.045731
105	CHART_6e00069600af0054003afc442f1f5daa	8	0.230947149	23726	21	0.606236266	-0.375289
113	CHART_74000733009000d3003e062c3d235daa	1	0.006922626	98941	1	0.006922626	0
124	CHART_89000cab00d80008003d242c3b235daa	3	0.013965843	147130	8	0.037242249	-0.023276
162	CHART_d8ff030400b800c60047832c33235daa	1	0.004462647	153481	1	0.004462647	0

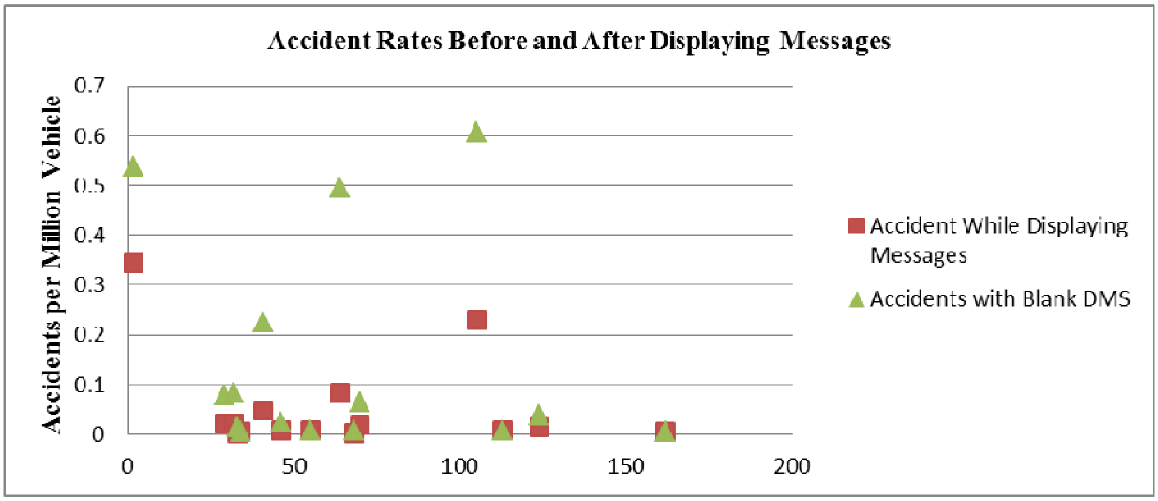


Figure 4.22. Comparison of accident rates while DMS are on and while blank

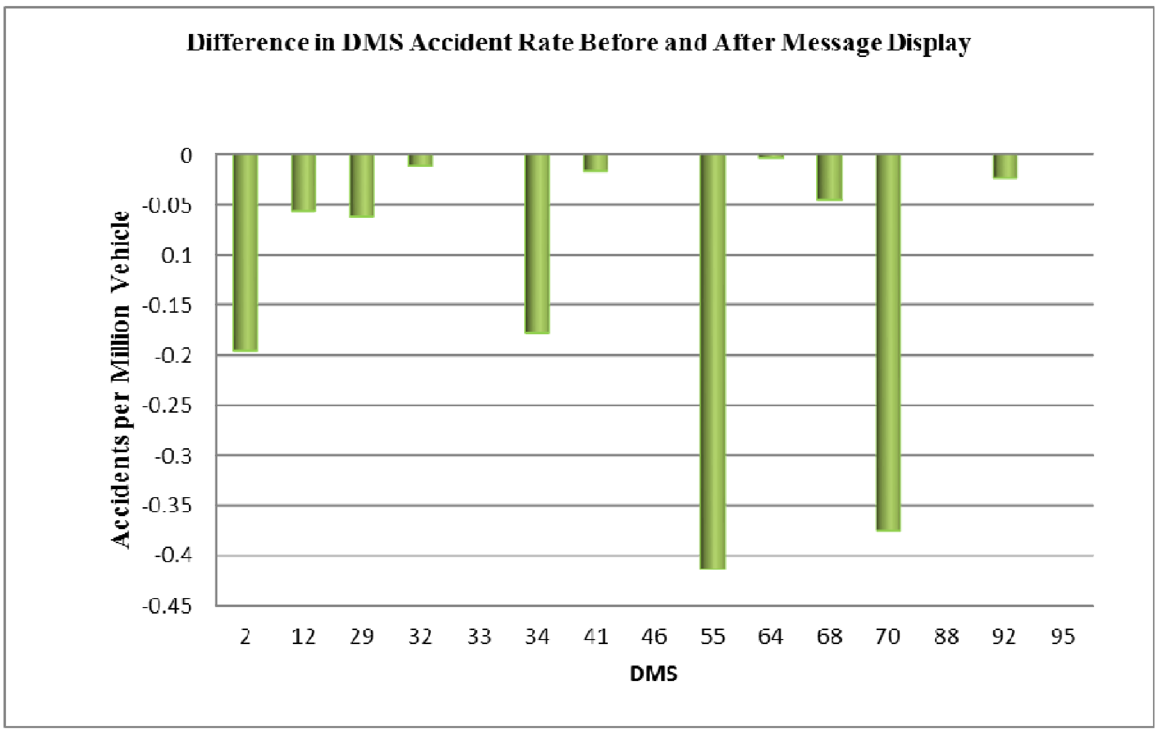


Figure 4.23. Difference of the accidents rates in on and off study

The results show that accident rates for DMSs that are displaying messages are less than or equal to the blank DMSs for all cases under study. The results of this on-and-off study support the outcomes of the previous sections and the fact that DMSs are not contributing factors in causing accidents.

4.10.1. Findings

A Repeated Measures Analysis of Variance is conducted to compare the mean accident rates in two conditions. The F-value of 6.73 and $P(F < 6.73)$ of 0.0212 for the one-way ANOVA with paired comparison suggests that null hypothesis is rejected with 98% level of confidence in favor of supporting the fact that the mean accident rate for active DMSs is lower than the rate of accidents for inactive DMSs. The SAS coding and the outcomes are presented in Figure 4.24.

Obs	Impact Area	DMSEffect
1	2	-0.19606
2	29	-0.05589
3	32	-0.06244
4	33	-0.01093
5	34	0.00000
6	41	-0.17864
7	46	-0.01696
8	55	0.00000
9	64	-0.41351
10	68	-0.00360
11	70	-0.04573
12	105	-0.37529
13	113	0.00000
14	124	-0.02328
15	162	0.00000

Figure 4.24. SAS outcomes for on and off study

The ANOVA Procedure

Number of Observations Read	15
Number of Observations Used	15

The ANOVA Procedure
Repeated Measures Analysis of Variance

Repeated Measures Level Information

Dependent Variable	DMSOn	DMSOff
Level of WorNoDMS	1	2

The ANOVA Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Anova SS	Mean Square	F Value
WorNoDMS	1	0.06369341	0.06369341	6.73
Error(WorNoDMS)	14	0.13243458	0.00945961	

Source	Pr > F
WorNoDMS	0.0212
Error(WorNoDMS)	

Figure 4.24 (Continued). SAS outcomes for on and off study

4.11. Accidents in DMS Impact Areas and Weather Conditions

The purpose of this section is to summarize and categorize accident characteristics in DMS areas. As mentioned before, weather conditions can induce accidents through reducing drivers' visibility. According to FHWA Road Weather Management Program, visibility impairments, precipitation, high winds and temperature extremes affect driver capabilities and operational decisions, traffic flow and crash risk. Considering the fact that this research concerns driver response to DMS messages, which is known to be an environmental factor, it would be necessary to investigate the accident in conjunction with weather conditions at the time of accident for active DMS. As Table 4.6 and Figure 4.25 show, there are only 4 accidents in the entire set of accidents within the impact area that happened in rainy and snowy conditions.

Table 4.6. Accidents in DMS areas and precipitation

Precipitation	Accidents in Impact Area #
Rain	2
Snow	2
None	45
other	1
Total	50

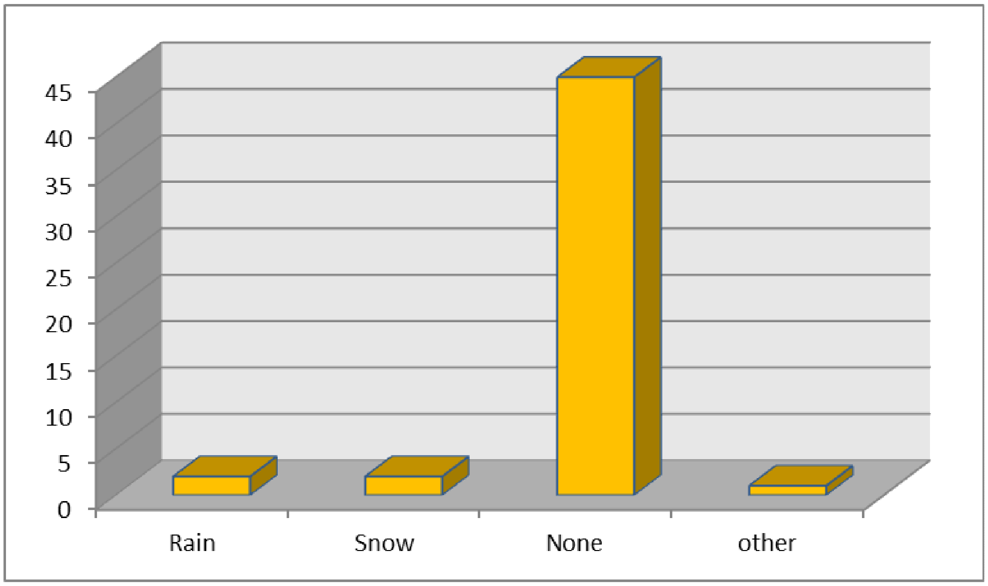


Figure 4.25. Frequency of accidents in different precipitation conditions

In spite of the concerns regarding lack of visibility of messages during wind gust condition, as shown in Table 4.7 and Figure 4.26, the statistical analysis regarding 43 accidents in impact area indicates there is not significant number of accidents in this condition.

Table 4.7. DMS accidents and wind gust

Wind Gust (mph)	Accidents in Impact Area #
0-10	32
10-20	9
20-30	2
Total	43

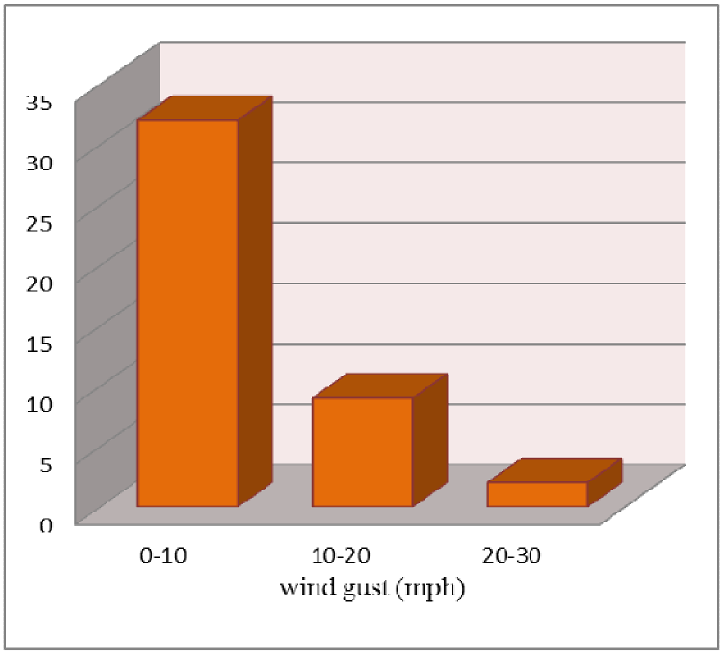


Figure 4.26. DMS accidents and wind gust

4.12. Accidents in DMS Impact Areas and DMS Characteristics

This section concerns statistical analysis of accident types in DMS impact areas in conjunction with type of messages and beacon operational status (on and off) of DMSs. Figure 4.27 shows that among 50 accidents in DMS impact areas, 35 collisions are property damage and 15 are personal injury.

There are some concerns that flashing beacons could distract drivers and eventually affect the driving performance. As Figure 4.28 shows, 10 accidents have happened while beacons were on which accounts for one fifth of the total number of accidents in the impact areas.

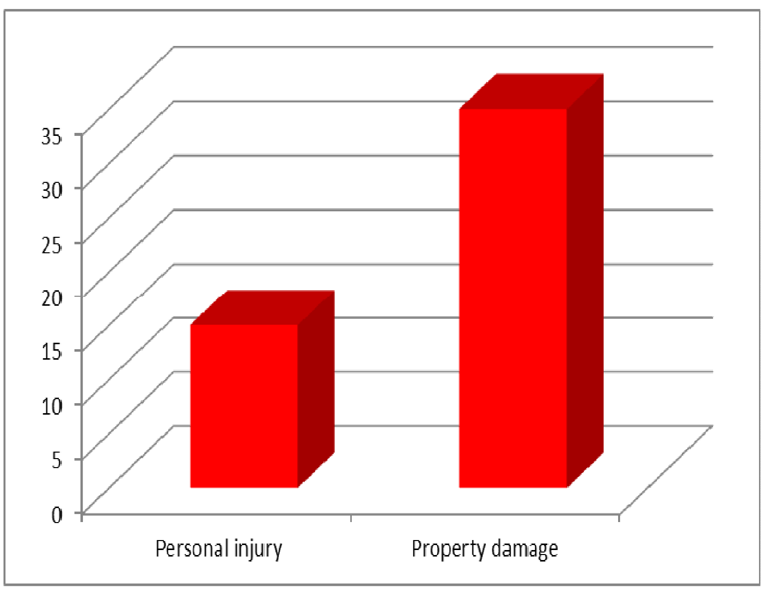


Figure 4.27. Type of accidents in DMS area #

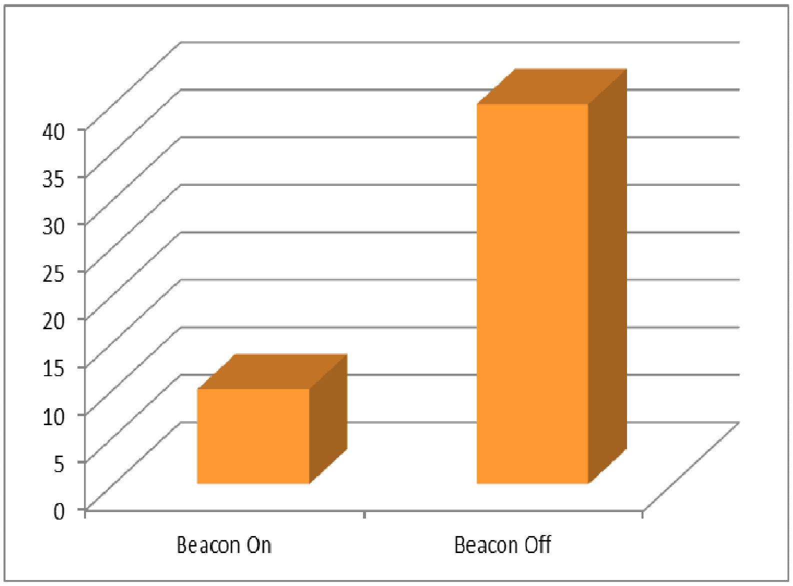


Figure 4.28. Number of accidents versus Beacon status

Analysis on displayed messages shows that 11 accidents occurred while danger/warning messages were displayed on DMSs. This amount for informative/common road condition messages and regulatory/non-traffic related messages are 22 and 17, respectively. Although some concerns exist that accident warning messages attract more attention from drivers (Wang et al, 2007), the least number of accidents in DMS impact areas belong to danger and incident warning messages category (see Figure 4.29).

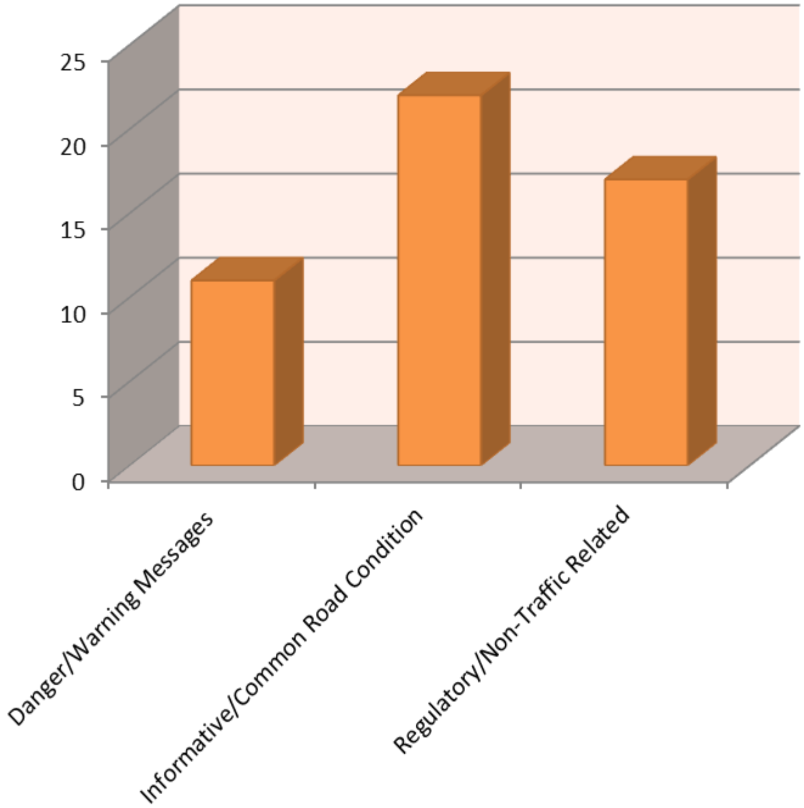


Figure 4.29. Number of accidents for DMS message types

Chapter 5: Conclusions and Directions for Further Research

5.1. Summary and Conclusions

This thesis evaluated localized safety impacts of highway Dynamic Message Signs (DMS). The accident data from 2007 to 2010 served as the ground-base for the analysis of road collisions in entire State of Maryland. The accident and log of messages data in study period was collected from the Center for Advanced Transportation Technology (CATT) Laboratory in the Department of Civil and Environmental Engineering at the University of Maryland, College Park and Coordinated Highway Action Response Team (CHART) reports for regions within the District of Columbia in Maryland. The roadway network map and AADT of roadway segments were obtained from Maryland Department of Transportation, State Highway Administration (SHA) and weather conditions databases were gathered from DOT archived data. To conduct this research we needed to acquire data from a variety of different sources. Dealing with huge and several databases with different data structure and coordination systems, confidentiality of police accident reports, processing of huge databases with tens of thousands of records and joining the databases based on two dimensions of time and location, were among the challenges which were successfully overcome in this research.

The accident database included 38,718 records, which were filtered, cleaned up, and from which data gap and outliers were removed. After data processing, number of accidents decreased to 23,842 records for the four-year study period. The accident database consisted of accident type (property damage, personal injury and fatality), address location and county, time and date of occurrence of accident and coordinates of accident location. Due to confidentiality concerns, access to police records and accident causes was not possible.

The DMS inventory was also provided by the CATT Laboratory. The DMS types in this research include permanently mounted overhead, roadside models and portable signs that are operated by CHART or Maryland Transportation Authority (MdTA). The DMS database with 184 records included DMS ID, longitude and latitude, address location and DMS type fields.

Since another important contributing factor to occurrence of crashes is traffic flow, AADT of the road segments was another factor that was taken into account for analysis. The AADT data was retrieved from Maryland's State Highway Administration volume maps of the state of Maryland for study period.

The accidents along with DMS locations and AADT database were projected to Maryland roadway map to perform spot analysis and to evaluate DMS influence on drivers' operational performance. An impact area of 900 feet was defined for each DMS based on the average size of electronic signs character and maximum visibility distance for the signs. A DMS was assigned to accidents within 900 feet of each DMS based on location and direction of DMS.

A case study was performed on Interstate 95 in Maryland which is a major highway. 70 samples of 900 feet segments along I-95 highway were chosen based on homogeneity in geometry. the number of accidents were counted for each segment and accumulated number of crashes in each segment was tabulated and used for regression analysis based on the fact that the segment is impact area or not, existence of interchange in the segment and AADT of the segment. The results of unbalanced two-way ANOVA revealed that P-value strongly rejects the hypothesis for lack of impact of Interchanges and showed that they actually do affect occurrence of accidents, while significance level for DMS impact was not high and made it clear that DMSs are not contributing factors in occurrence of accidents. The outcome of Poisson regression supported these results, too. The results for both methods converged to the point that interchanges and AADT are important factors on accidents, but do not show any relationship between occurrence of presence of DMSs and occurrence of accidents.

Another main factor in causing accidents is lack of visibility due to adverse climate situation. Since precipitation, wind gust and severe weather conditions could have negative impact on visibility of messages while driver tries to read the messages, statistical analysis was performed regarding this factor. For simplicity, the area of research was divided into 5 regions of north, south, west, east and Washington, DC. The nearest central weather tower station in each region was assigned to represent the weather condition in each region. The database was accumulated for four-year study period (2007-2010). Each accident in database was joined with weather stations database. The weather database was joined to the main database based on the proximity of the closest weather tower station to the time and location of each accident. The matching process was performed using SQL queries coded in C++.

The database for log of messages was acquired from the CATT laboratory. This database contained the entire messages that were displayed on all of the DMSs in State of Maryland during the time period of 2007 to 2010 including 1,047,586 records of messages and consisted of DMS ID, time of displaying the message, the message and beacon data fields.

The message log database was imported in SQL server along with the main database. For each accident if it was located in impact area, the assigned DMS was matched with the message displayed at the time of occurrence of accident. Likewise the weather data, the matching process was conducted using SQL queries coded in C++. The integrated database consisted of 23,842 records for accident during study time period. There were 298 accidents located in 900 feet proximity to DMSs. From all accidents in impact area, there were 50 accidents during which, the dynamic message signs were displaying messages. For the remaining accidents, the DMSs were blank. The data were analyzed in several aspects.

The paired t-test analysis at 95% confidence level for difference of mean accident rates on DMS impact areas and their subsequent 900 feet segment of buffer zones with t-statistic of -0.65 and p-value of 0.5245 showed that DMSs do not increase accident occurrence. The mean of the difference of the two accident rates was -0.013.

The one-way ANOVA analysis with pairwise comparison test in on-and-off study for 15 DMSs to compare accident rates of active and inactive DMSs with F-value of 6.73 and $P(F < 6.73)$ of 0.9995 showed that the mean accident rate of active DMS is lower than the inactive DMSs at 98% level of confidence.

The statistical analysis of accidents in conjunctions with weather conditions showed that, there are only 4 accidents in the entire accidents of impact areas that fall in rainy and snowy conditions. 32 out of 43 accidents were in wind gust with 0-10 mph condition, 9 out of 43 were in wind gust with 10-20 mph condition and 2 of the 43 accidents were in wind gust with 20-30 mph speed condition.

The statistical analysis of accidents in conjunction with DMS characteristics revealed that among 50 accidents in DMS area, 35 collisions are property damage and 15 are personal injury.

10 accidents occurred while beacons were on which accounts for one fifth of the accidents. Analysis on displayed messages showed that 11 accidents occurred while danger/warning messages were displayed on DMSs. This number for informative/common road condition messages and regulatory/non-traffic related messages was 22 and 11, respectively. Although some concerns exist that accident warning messages attract more attention from drivers, the least number of accidents in DMS areas belonged to danger and incident warning messages.

In summary, the findings from all evaluations converge and indicate that DMS could be a safe tool for disseminating real-time travel information to motorists and these signs do not have significant adverse effects on driver's operation and causing accidents. This thesis focused on DMS operations in the state of Maryland and the methods employed for evaluation are extendable to other locations if the data are available.

5.2.Future Research

The broad range of subjects for future study provides opportunities and challenges for researchers. The research could be further completed if study area encompasses several states. Future research in this area may be improved through investigating the issue through simulation and site human factor analysis. Also it would be of interest to improve DMS design (such as message design, size, color, lengths and number of panes and speed of switching between messages) to provide better driver's understanding of messages specially elder or bilingual drivers. Investigation on the impacts of displaying messages on newly installed DMSs as well as the impact analysis of DMSs on road curvatures could be other topics for future research. Beside it would be of interest to investigate the impact differences in daylight and-nightlight situations. Another direction for future research in the extension of this thesis is to investigate the impact of the incident messages and to provide motorists with information ahead on tailgating and secondary accidents close to the incident location. Moreover, the integrated database could be used to investigate the impact of weather conditions on occurrence of road accidents.

Finally, optimization of displayed messages and DMS location considering traffic flow, geometry of the roadway, proximity to interchanges and reducing drivers' mental processing time to perceive environmental factors and speed up drivers' response could be another interesting topic for future study. Moreover, a cost and benefit analysis on installing DMSs on roadways clarify the concerns regarding expenses and values of the signs. These directions for future studies would help transportation engineers and planners improve DMS operations and eventually improve transportation network management with smoother traffic flow conditions.

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