Evaluation of Traveler Diversion Due to En-Route Information

Final Report

by

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16. Abstract

Since the introduction of Intelligent Transportation Systems (ITS), the transportation engineering community has tried to identify the benefits of these systems in concrete terms. One of these ITS strategies is a Dynamic Message Sign (DMS). This report details an attempt to determine the effect a DMS system has on driver behavior at a site selected was in the Hampton Roads area of Virginia. The scenario studied was the choice a traveler has to change his/her route from the Hampton Roads Bridge Tunnel to the Monitor Merrimac Bridge Tunnel based on messages displayed on the DMS system. Data was collected on the DMS system and volume data was obtained using loop detectors, over a period from August 1998 to July 1999. This data was processed and the difference between the percentage of drivers turning towards the Hampton Roads Bridge Tunnel when the DMS system was and was not in use was calculated. This difference is referred to as the diversion percentage. The average diversion percentage calculated was very low. Reasons for this result include the 'weak' message displayed on the system, the unwillingness of drivers to divert, and the distance from the secondary route. Sensitivity analyses performed on the data showed that certain variables affect diversion percentage. Drivers were more likely to divert during Thursdays and Fridays, summer months, off-peak times, and instances when high traffic volumes existed. A secondary analysis is performed on recent data after a change was made in the usage of the DMS system. The secondary analysis suggests that the newer messages created a larger amount of diversion, although this cannot be proved due to the small amount of data. Another secondary analysis compares two different methodologies for determining diversion. The results from this report are limited to the scenario studied and should not be applied to other situations where a DMS system is used to divert drivers.

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ABSTRACT

Since the introduction of Intelligent Transportation Systems (ITS), the transportation engineering community has tried to identify the benefits of these systems in concrete terms. One of these ITS strategies is a Dynamic Message Sign (DMS). This report details an attempt to determine the effect a DMS system has on driver behavior at a site selected was in the Hampton Roads area of Virginia. The scenario studied was the choice a traveler has to change his/her route from the Hampton Roads Bridge Tunnel to the Monitor Merrimac Bridge Tunnel based on messages displayed on the DMS system. Data was collected on the DMS system and volume data was obtained using loop detectors, over a period from August 1998 to July 1999. This data was processed and the difference between the percentage of drivers turning towards the Hampton Roads Bridge Tunnel when the DMS system was and was not in use was calculated. This difference is referred to as the diversion percentage. The average diversion percentage calculated was very low. Reasons for this result include the 'weak' message displayed on the system, the unwillingness of drivers to divert, and the distance from the secondary route. Sensitivity analyses performed on the data showed that certain variables affect diversion percentage. Drivers were more likely to divert during Thursdays and Fridays, summer months, off-peak times, and instances when high traffic volumes existed. A secondary analysis is performed on recent data after a change was made in the usage of the DMS system. The secondary analysis suggests that the newer messages created a larger amount of diversion, although this cannot be proved due to the small amount of data. Another secondary analysis compares two different methodologies for determining diversion. The results from this report are limited to the scenario studied and should not be applied to other situations where a DMS system is used to divert drivers.

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CHAPTER 1 - INTRODUCTION

RATIONALE

With the introduction of advanced computer and communication technologies, transportation engineers and officials have more tools available at their disposal than ever before. Initiatives that integrate communication and information technologies in order to increase the safety and efficiency of the transportation network are collectively known as Intelligent Transportation Systems (ITS). Since ITS strategies are relatively new, a challenge to the transportation engineering community is to identify their benefits in concrete terms. The purpose of this report is to evaluate a specific type of ITS in the field, and help define the effect it has on drivers.

The type of ITS evaluated in this report is a type of Advanced Traveler Information System (ATIS). An ATIS is a system that gathers information on the condition of the transportation system and disseminates this information to travelers through various media. An ATIS can come in many forms; a generic flowchart of one is presented in Figure 1.

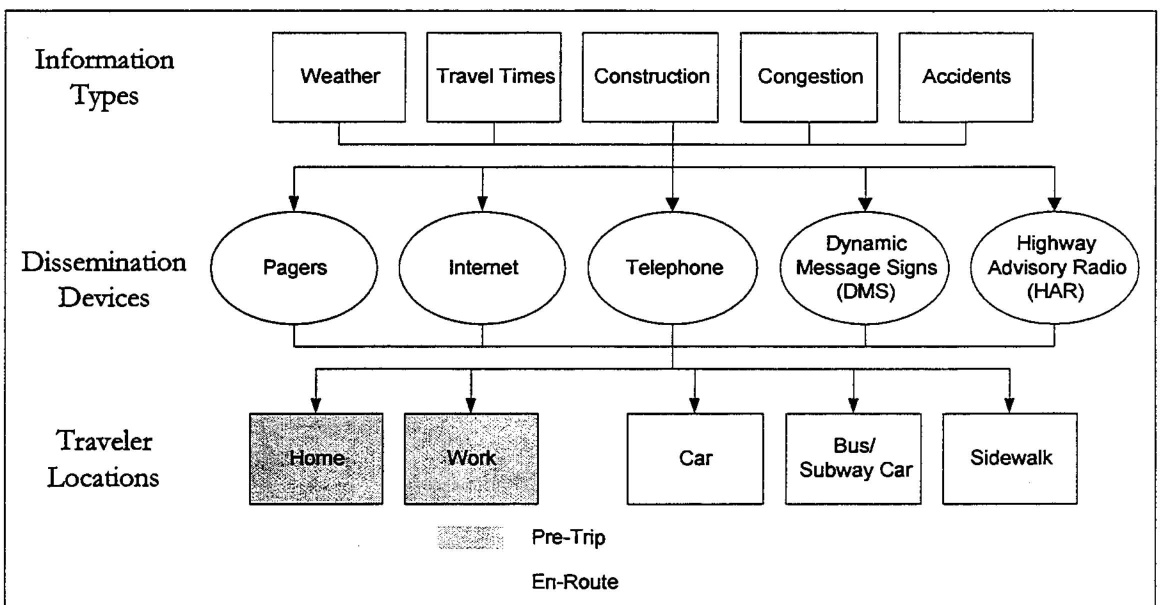

Figure 1 - Generic ATIS Flowchart

An example of an ATIS is the SmarTraveler Web Site (http://www.smartraveler.com) which dispenses traveler information for various cities across the country. The information available on the SmarTraveler Web Site is known as pre-trip traveler information, or information presented to the traveler before the mode of transportation and/or route to their destination is chosen. Another type of ATIS is an en-route traveler information system, which is intended to provide information to travelers already on their chosen route. The goal of en-route information is to make travelers aware of unexpected delays, and help them select alternative routes to their destinations. An example of an en-route information system is highway advisory radio.

The type of ATIS evaluated in this report is a Dynamic Message Sign (DMS), an en-route traveler information system. As seen in figure 2, a DMS is an electronic sign visible from the highway. Traffic engineers can send messages to the DMS from a control center.

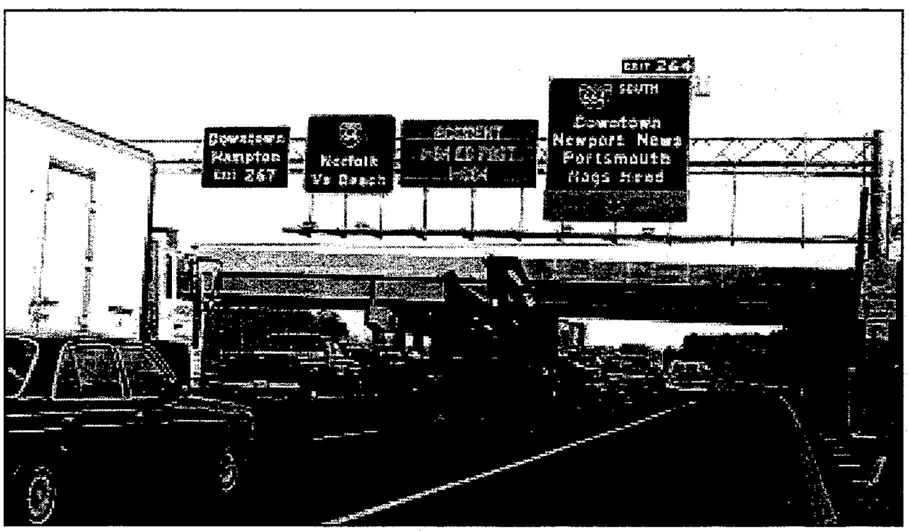

Figure 2 - Picture of a DMS Sign

Dynamic message signs have been installed in numerous cities across the country. Unfortunately, communities are having trouble determining the effects and benefits of these systems. Studies have been performed at the system wide level showing improvements in the transportation system as a whole, but very few studies have been performed to determine if a dynamic message sign influences driver behavior on a microscopic level. Communities interested in predicting the effect of installing a DMS system on an intersection or specific stretch of roadway would benefit from a study on the effect of a dynamic message sign on drivers' tendencies.

The aspect of driver behavior evaluated in this report is diversion from a primary to a secondary route while en-route to a chosen destination. A simple diagram of a diversion scenario is presented in figure 3.

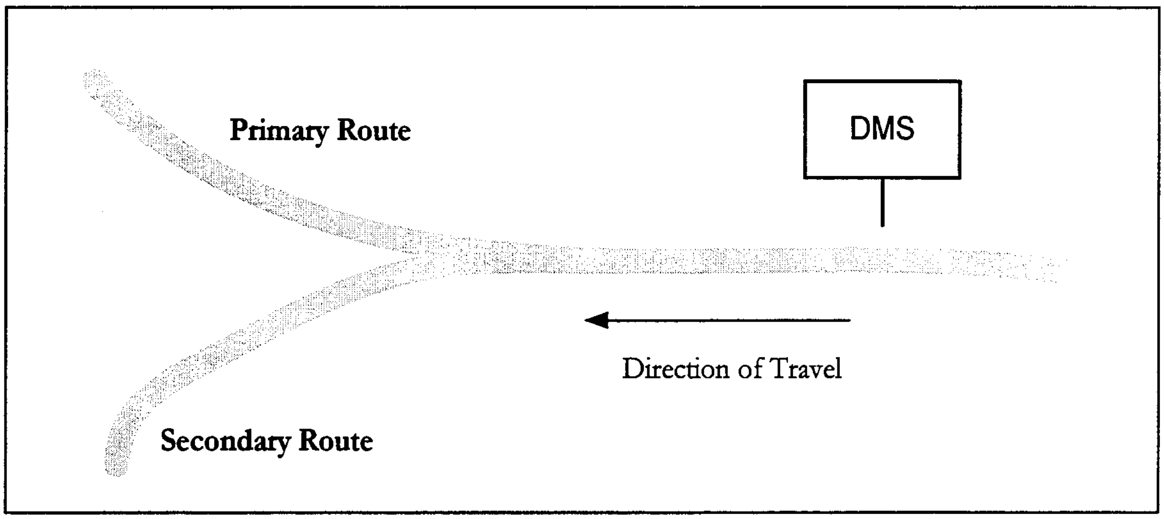

Figure 3 - Simple Diversion Scenario

Transportation engineers and planners install dynamic message signs with several objectives. One such objective is that dynamic message signs alert drivers to a problem and divert them to a secondary route. The scenario chosen for study in this report is an interchange in the Hampton Roads area of Virginia, and is described in Chapter 3.

One of the most common sources of information about the highway transportation system is a loop detector. Loop detectors are placed within the pavement of certain roads and highways to gather data about the characteristics of the traffic flowing across the detector. If these detectors are placed correctly, transportation engineers can develop an improved picture of traffic volumes on the road network.

A loop detector works using an electrical property known as inductance. A loop usually consists of one or more turns of an insulated wire formed into a loop and placed in a shallow slot sawed into pavement. Energy is passed through the wire loop, creating an electrical circuit. This electrical circuit creates a magnetic flux, which is measured and recorded. The level of this inductance changes when metal objects are near the loop. Thus, when a car passes over the loop it produces a increase in the inductance measurement. These readings can be interpreted into various useful variables for traffic engineers, such as volume, speed and occupancy.

This report uses volume data collected from loop detectors. It compares the data collected by detectors with information describing when the DMS system was used to divert drivers. Specifically, this report compares volume data from times when the DMS system was in use with volume data from similar times when the DMS system was not in use. Analyses were performed to quantify the amount of diversion caused, in part, to the DMS system.

ANALYSIS METHODOLOGY

The methodology used for the analysis in this report consisted of six steps. Figure 4 outlines this methodology. First, a site is selected for the analysis. For this report, a site needed three primary characteristics: good primary and secondary routes, a DMS system used to divert drivers, and available traffic volume data. Second, once the site is selected, the DMS and traffic volume data is collected. The DMS data is necessary for knowing what message is displayed and when. Traffic volume data is necessary to determine the effects of the DMS system on traffic patterns.

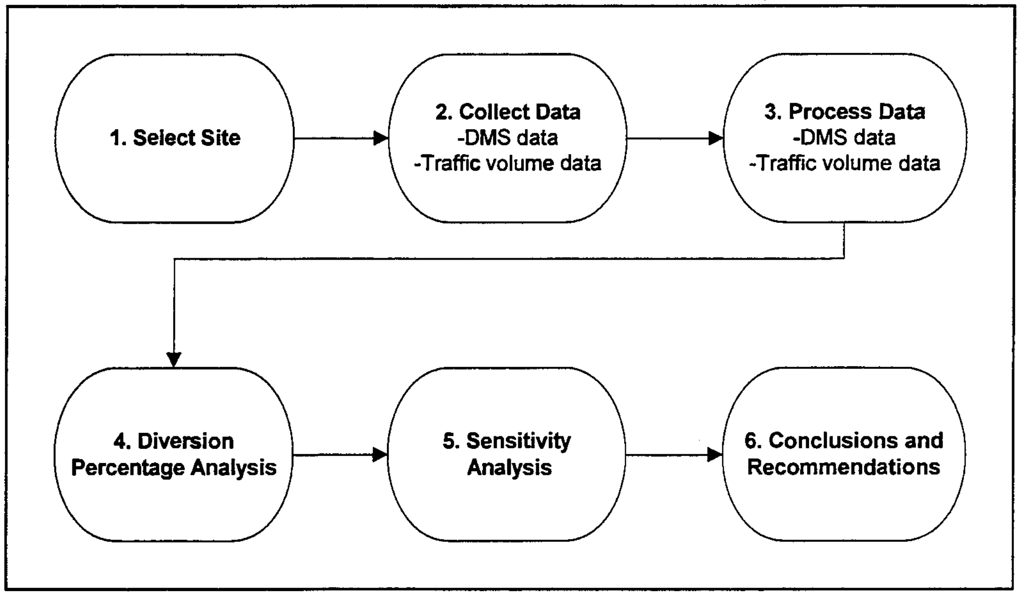

Figure 4 - Analysis Methodology

Once the data is collected, it is processed. The DMS data is searched and selected messages, dates and times are recorded to be studied. The traffic volume data is then matched up to the DMS data when the DMS system either is or is not in use. Then, the diversion percentage analysis is performed on the processed data to determine the amount of deviation that occurs when the DMS system is in use. Next, sensitivity analyses are performed on the data to determine how much certain variables affect diversion percentage. Finally, conclusions are drawn from the data analyses and recommendations are made on both future research and possible upgrades to the DMS system.

OBJECTIVES

The purpose of this report is to evaluate the diversion of travelers from a primary to a secondary route using field volume data when the DMS system is used in an attempt to divert drivers from the HRBT to the MMBT. The objectives of this study are:

- Determine the effectiveness of devices, such as a DMS, in impacting the route selection of drivers.
- Document the effects of a DMS on the behavior of drivers to aid past and future research.
- Determine areas of future research.

BENEFITS

This project benefits transportation officials, decision-makers, and users of the transportation network. Transportation officials benefit because the results from this project help determine how to use en-route information more efficiently. The results of this project identify the effects of a DMS on driver behavior, thus allowing officials to predict the effects using a DMS will have on the highway network. Decision-makers thinking about building an ATIS or improving an existing one can use the results from this project to guide them. The results of this analysis make the evaluation of benefits of a DMS system easier. Finally, users of the transportation network benefit from a more efficient use of tax dollars and the improvements made to the transportation system.

In a dissertation by Adel Sadek written in 1998, driver behavior was one of the recommended areas of future research. The dissertation developed an artificial intelligence based architecture for a real-time traffic routing decision support system. The system would be used to ease congestion by developing routing strategies that attempt to optimize the performance of the highway network. During the research performed for the dissertation, the Hampton Roads Smart Traffic Center was not yet complete. Thus, Sadek could not incorporate data on drivers' route selection behavior. Sadek recommends an analysis of the DMS system's effect on driver behavior for future research. The results of such research could be appended to the dissertation to create an improved real-time traffic routing decision support system (Sadek 1998). This project takes the first step in analyzing the effects of the Hampton Roads DMS system on driver behavior.

CONTENTS OF REPORT

Chapter 2 is a review of relevant literature. It focuses on two subjects; research performed to measure impacts of general advanced traffic information systems and research performed to determine the benefits and impacts of DMS systems. Chapter 3 presents a detailed description of the scenario to be analyzed. It contains diagrams of the interchange studied and details on the DMS and loop detector systems. Descriptions of data collection and pre-processing are contained in chapter 4. Chapter 5 discusses the analyses performed, and subsequent results. Chapter 6 describes two secondary analyses performed after the results from Chapter 5 were determined. Conclusions and recommendations are listed in chapter 7.

CHAPTER 2 - REVIEW OF RELEVANT LITERATURE

MEASURING ATIS IMPACTS AND BENEFITS

A report sponsored by the Department of Transportation concerning the performance and results of ITS discusses the different benefits of ATIS. Among the benefits discussed are reduction in crashes and fatalities, improved use of time and throughput, decreased cost, improved customer satisfaction, and reduced emissions and fuel consumption (Cheslow 1997). Another report, prepared by Apogee/Hagler Bailly for the Department of Transportation, is very similar. In this report, general ATIS benefits are presented, using specific examples. Most successful ATIS practices that are cited concern pre-trip traveler information (Apogee/Hagler Bailly 1998).

Research has been conducted on traveler response to information based on survey answers. In 1991, a study in Chicago surveyed commuters about their response to incident-induced congestion (Khattak et al. 1991). Madanat et al. used mathematical modeling, along with survey results, to identify factors explaining drivers' route diversion behavior. It was found that travel and social characteristics, as well as the type of en-route information provided were important variables in driver behavior (Madanat et al. 1995). Polydoropoulou et al. performed a study on the type of traveler information drivers prefer. Based on survey results different types of en-route traveler information were compared (qualitative, quantitative, prescriptive, and predictive). The conclusion found that travelers prefer specific quantitative delay information (Polydoropoulou et al. 1996). A similar study concerned pre-trip information (Khattak et al. 1996). A paper by Mehndiratta et al. investigated consumer demand through surveys in major cities (Chicago, Seattle and Boston). An interesting conclusion of these surveys was the timeliness of the information and the amount of route coverage are the two most important aspects of en-route traveler information (Mehndiratta et al. 1999). Wells and Horan prepared a report using surveys in Southern California. One of the report's findings was that although travelers in Southern California were exposed to pre-trip traveler information, it did not help them avoid or respond to congestion. The existence of some consumer demand for an improved ATIS including in-car navigation and more frequently updated information, and definite public support for tax dollar spending on such initiatives as computerized traffic control, and improved traffic information collection are among the other conclusions (Wells and Horan 1999)

A report by Ng and Mannering used a full-size fixed-based driving simulator to collect data on drivers' speed behavior under several different advisory information conditions. The four conditions evaluated were driving with in-vehicle information, driving with dynamic message sign information, driving with both in-vehicle and dynamic message sign information and driving with no information. The study showed that for long distances no significant differences in speed and standard deviation of speed existed, regardless of the traveler-information system used. For shorter distances, the study observed that there were significant changes in speed. The authors suggest that this occurs because drivers compensate for a period of slowing in response to advisory information by driving faster (Ng and Mannering 1998).

A paper by Levinson et al. attempts to place value on an ATIS to the user. The paper's findings showed that ATIS provided travel time benefits to both specific users as well as society overall. However although it may increase the time for the section of travelers without information. The value of an ATIS is greatly increased during unexpected congestion (Levinson et al. 1999).

MEASURING DMS IMPACTS AND BENEFITS

A study performed in Finland (Rämä 1999) tested the ability of an en-route traveler information system to reduce speeds during poor weather conditions. Two types of signs were used in the study; a weather-controlled variable speed limit sign and a dynamic message sign that could display a 'slippery road' symbol along with normal text messages. Loop detectors were used to measure speeds under various conditions. These speeds were then compared to the state of the message signs and patterns were sought. The report's main conclusion was that the weather-controlled system decreased both the mean speed and the standard deviation of speeds. On highways without the weather-controlled system, speeds also decreased, but not as much as they did on roads with the advanced information system. The author was hesitant to call the system a success, as the decrease in speeds was not significant. The average speed reduction was only 3.4 km/hour in the winter, and the author clearly states that, "The combined effects of the lowered speed limit and the slippery road sign were smaller than expected". The final recommendation of the report was that the concept of the system was a success. It reduced speed during adverse road conditions, although the reduction in speed was not sufficient to make the DMS system economically profitable on a road with low traffic volumes (such as the road used in the study).

Some research on dynamic message signs is concerned with the type of messages displayed. A report prepared by Hustad and Dudek researched the ability of New Jersey drivers to understand abbreviations placed on dynamic message signs. The main conclusion was that general traffic abbreviations were understood well by most drivers, but abbreviated names of roads and attractions within New Jersey were understood less by New Jersey drivers. Furthermore, non-New Jersey drivers were even less likely to understand the New Jersey-specific abbreviation than native drivers (Hustad and Dudek 99).

A study performed in the Netherlands evaluated the system wide effects of the installation of fourteen dynamic message signs in Amsterdam. The study had three parts; first, the relation between the messages displayed and the travel times experienced by drivers was analyzed. Next, a survey was used to determine the perceptive reliability and usefulness the system had on drivers. Third, a network-wide analysis of aggregate performance indicators, like queue length, distance traveled and time spent on the network was conducted (Kraan et al. 1999). The messages disseminated by the system provided information on the queue lengths of routes in the system. This information, if interpreted correctly by drivers, was found to be an accurate indicator of travel time. The user acceptance survey showed that both drivers and operators stated that the DMS system provided understandable and reliable information. The survey results showed that two-thirds of drivers changed their routes based on DMS information. It must be noted that results from surveys are questionable because the portion of the population responding might not be an accurate sample. In addition, people often exaggerate their usage of transportation systems, such as dynamic message signs on surveys. The impact assessment study showed that total congestion slightly decreased and traffic performance slightly increased. Drivers chose to divert from congested routes to slightly longer alternative routes. Delay decreased during rush hour traffic in both morning and evening. Overall, the findings of the study suggest that the DMS system had a positive effect on the network performance of the Amsterdam freeway system, because travel times became more reliable (Kraan et al. 1999).

A report in 1999 attempted to develop an algorithm that would determine the optimal diversion rates for a DMS system. The authors believed that there was a lack of set procedures effectively outlining the operation of dynamic message signs (Valdes-Diaz et al. 1999). The proposed optimal rates sought by the authors were rates that diverted enough drivers to improve system performance. For example, if one route is congested and a substantial amount of drivers divert to an alternate route, the alternate route will become congested as well, thus decreasing the performance of the network as a whole. To determine these rates of diversion, a set of simulation experiments was conducted. The simulations that were run under different DMS system diversion rates showed that an optimal time did exist under which travel times can be improved without hurting overall network performance.

SUMMARY OF LITERATURE REVIEW

Several studies have been performed concerning the benefits and impacts of an ATIS. These include: reduction in crashes and fatalities, improved use of time, decreased cost, improved customer satisfaction, and reduced emissions. Surveys have been used to determine drivers' opinions on ATIS. Some conclusions that were found are:

- Travel and social characteristics, along with the type of en-route information provided are important variables in driver behavior
- Travelers prefer specific quantitative delay information
- The two most important aspects of en-route traveler information are the timeliness of the information and the amount of route coverage
- Although travelers in Southern California are exposed to pre-trip traveler information, it did not help them avoid or respond to congestion
- Consumer demand exists for improved ATIS, including in-car navigation and more frequently updated information

Simulators have also been used to perform research on driver behavior. Conclusions found by these research projects include:

- For a short distance, significant changes in speed occurred when drivers encountered en-route information. However, this might occur because drivers were compensated by driving faster after slowing down in response to the advisory information
- For long distances, no significant difference in speed existed regardless of the type of traveler information system used.

Research has been performed on DMS systems specifically. This research has been performed on the content of the signs, the ability of messages to affect drivers' speed, and the system wide effects of a DMS. Several of the research findings are:

- A DMS system in Finland was not economically profitable on a road with low traffic volumes
- Most drivers understand general traffic abbreviations, but abbreviated names of local roads and attractions are not understood well by most drivers
- Two-thirds of drivers responding to a survey stated they altered their routes because of a DMS system implemented in the Netherlands.
- The same DMS system implemented in the Netherlands slightly decreased congestion and slightly increased traffic performance.
- The overall findings of the study concluded that the DMS system had a positive effect on the freeway network performance

CHAPTER 3 - SCENARIO DESCRIPTION

THE HAMPTON ROADS AREA OF VIRGINIA

The body of water located between the mouth of the James River (to the west) and the Chesapeake Bay (to the east) is known as "Hampton Roads". This natural harbor is located in Southeastern Virginia and the name "Hampton Roads" has been adopted to refer to all of the metropolitan regions surrounding the harbor, as shown in Figure 5.

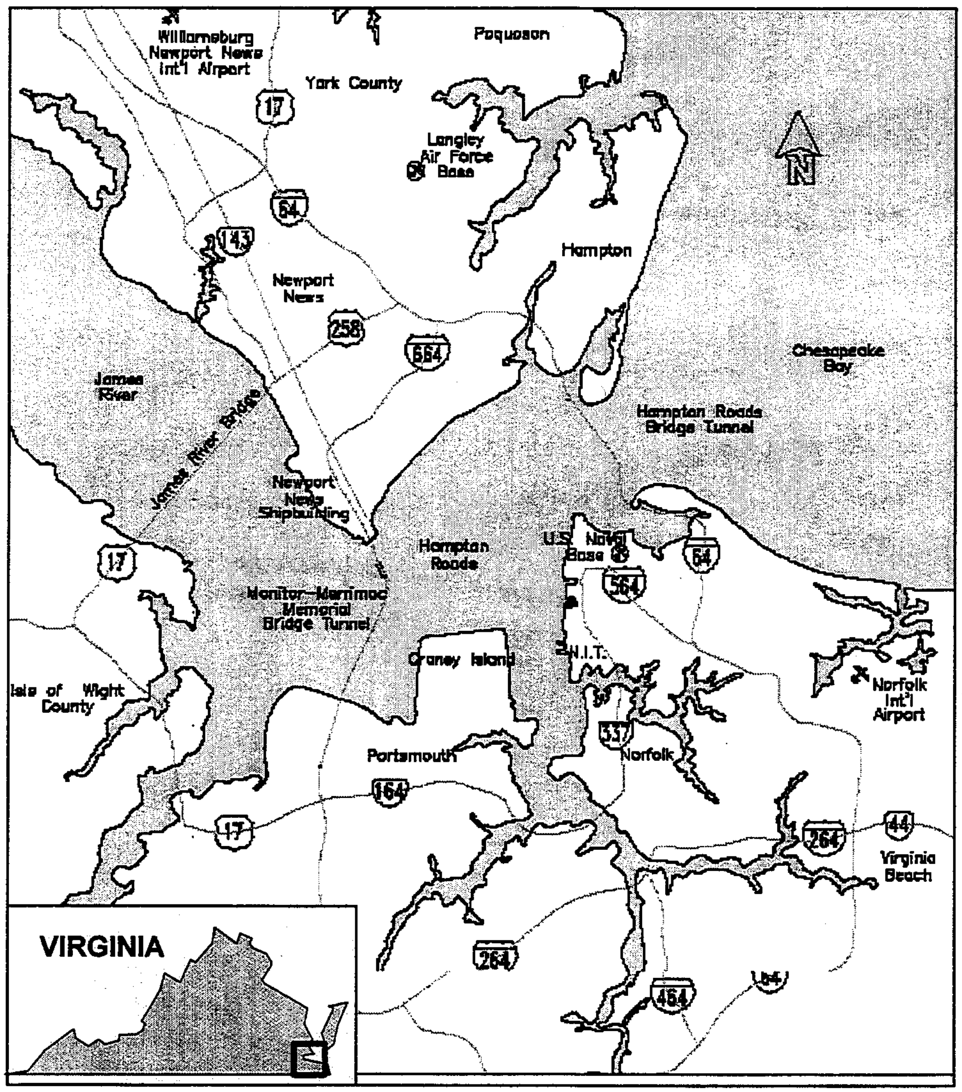

Figure 5 - Map of Hampton Roads

North of the harbor lie the cities of Hampton, Poquoson, and Newport News, as well as York County. South of the harbor are the cities of Chesapeake, Norfolk, Portsmouth, Suffolk, and Virginia Beach, as well as Isle of Wight County.

DIVERSION SCENARIO

When travelers leave the Virginia Beach area and want to travel across the Hampton Roads harbor they have two primary choices; the Hampton Roads Bridge Tunnel (HRBT) and the Monitor Merrimac Bridge Tunnel (MMBT). A traveler must decide which crossing to take before reaching the intersection of Route 44 and Interstates 64 and 264, shown in Figure 6. The majority of drivers chose to take the HRBT, because it is closer in proximity. During times when the HRBT is congested, a DMS system is activated in an effort to divert drivers towards the MMBT. The diversion scenario analyzed in this report is when travelers are alerted to congestion in the HRBT and divert towards the MMBT. The HRBT is designated the primary route, and the MMBT is considered the alternate route.

The highways within the Hampton Roads area are operated by a traffic management center, known as the Hampton Roads Smart Traffic Center. The Smart Traffic Center has several duties, such as collecting information on the local highways, dispatching appropriate vehicles when incidents arise, and disseminating traveler information. The Smart Traffic Center uses various tools to accomplish these goals, two of which are dynamic message signs and loop detectors. Figure 6 depicts the location of the highways the Center monitors, and the positions of their loop detectors and dynamic message signs.

As shown in Figure 6, three message signs are located between Virginia Beach and the I64/44 interchange. In addition, numerous loop detectors record traffic conditions along Route 44 and the interchange.

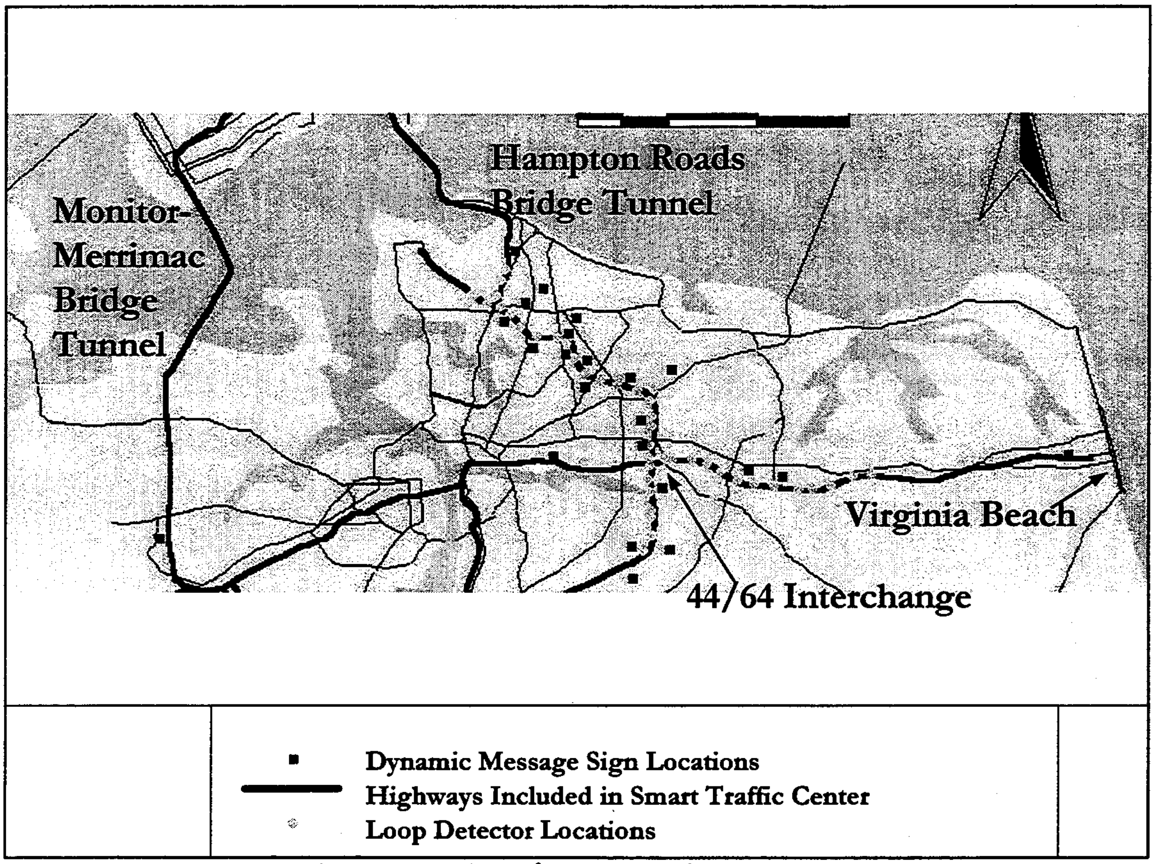

Figure 6 - Locations of Detectors and Message Signs

This report specifically focuses on these three signs and the messages relayed to them. The Smart Traffic Center used two standard messages when the HRBT was congested. Based on the amount of delay in the HRBT, one of the messages was used. The first message used was "I64 TUNNEL CONGESTED / EXPECT DELAYS". This message was used often to inform drivers of delays of estimated time of 30 minutes or less. The second message used was "I64 TUNNEL BLOCKED / USE ALTERNATE ROUTE". This message was used less frequently to inform drivers of blockages in the tunnel.

The three signs used all three available lines and were of the "flipdisk" variety. The first sign, closest to Virginia Beach, is located at the intersection of Birdneck and 264 on the right-hand shoulder. The middle message sign is located right before the Witchduck exit on

Route 44 over the highway's high occupancy vehicle (HOV) lane. The third DMS is positioned immediately after the Witchduck on-ramp, over the HOV lane. The first two signs defaulted to blank messages when not used to report incidents. The third sign defaulted to HOV information when not used to convey diversion information.

SELECTED SITE

The interchange studied in this report is the Route 44/Interstate 64 interchange. Figures 7 and 8 show an aerial view of the interchange and a diagram of the interchange with selected loop detectors and off ramps.

The length of the primary route is 18.38 miles. This distance is measured from the Route 44 and I64 interchange on the south side of the river to the I64 and I664 interchange on the peninsula north of the river, using the HRBT. The secondary route, over the MMBT is 38.03 miles long (Sadek 1998). This route has the same starting and ending points as the primary route. According to the Hampton Roads Crossing Study Traffic Model Methodology Report, the average speed on an interstate highway within a suburb south of the river was 55.4 miles an hour during the AM peak (54.6 during PM peak) in 1990 (COMSIS 1996). Thus, the 19.65 mile difference is equivalent to approximately 21 to 22 minutes of travel time.

The Hampton Roads Crossing Study also contains information about the split of drivers who take the HRBT and the MMBT. This data was collected in 1990 for each bridge tunnel and is organized by a driver's origin locality south of the river and destination locality north of the river. Both the estimated number of trips per day and surveyed number of trips per day are included in the report. Since the DMS signs studied in this report begin on route 44, the origin locality chosen for this project is Virginia Beach.

Figure 7 - Aerial Picture of Selected Site

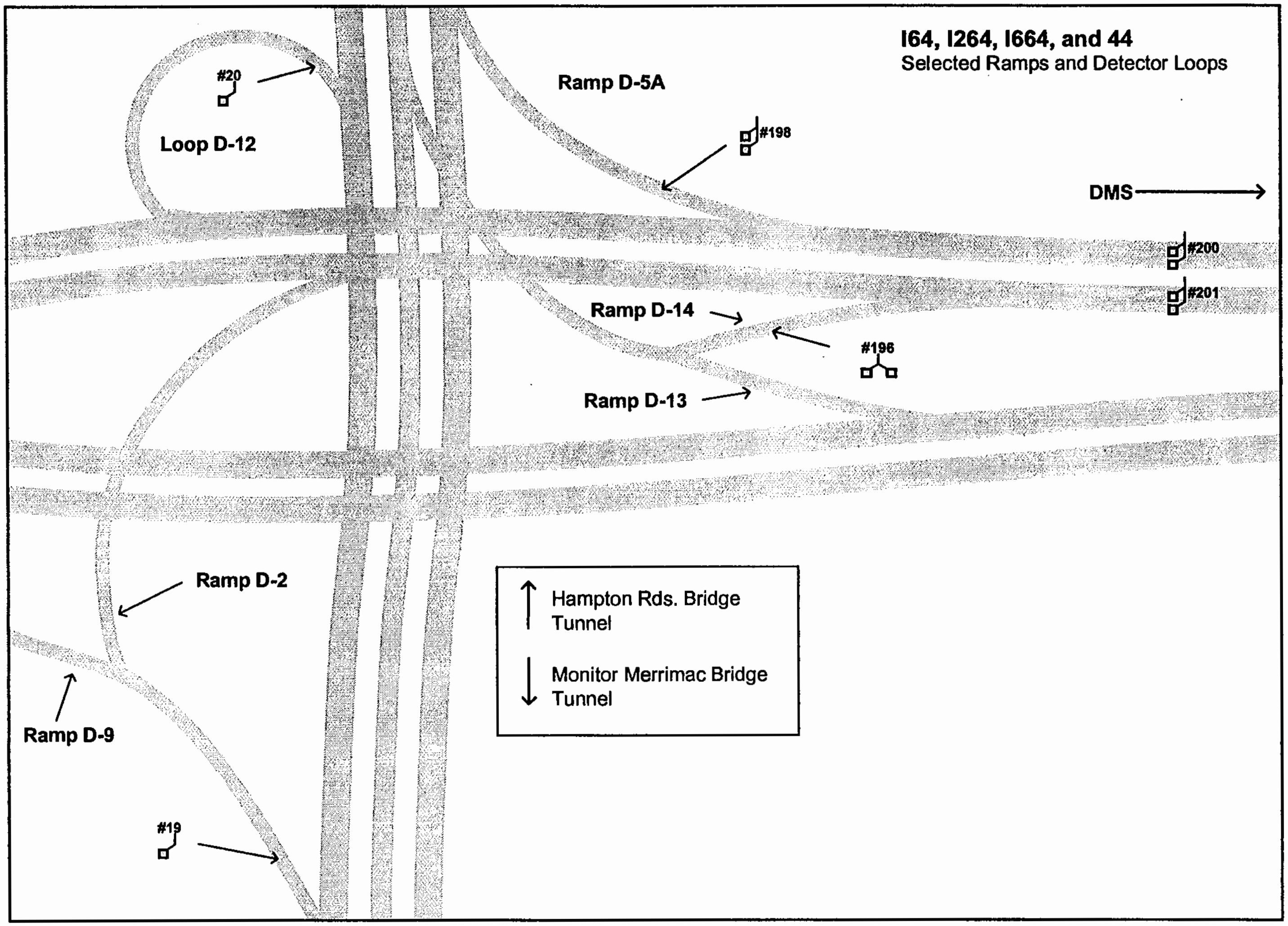

Figure 8 - Diagram of Selected Site

The destination locality for this report is any destination north of the river, as the destination of the driver was not taken into account in this project. A summary of the pertinent information contained in the Hampton Roads Crossing Study is presented in Figure 9 (COMSIS 1996).

Trips per Bridge Tunnel (per day, 1990)			
Origin	**Destination**	**Bridge Tunnel**	**Trips**
Estimated Trips			
V. Beach	North Side	Hampton Roads	12,975
V. Beach	North Side	Monitor Merrimac	958
Survey Trips			
V. Beach	North Side	Hampton Roads	9,870
V. Beach	North Side	Monitor Merrimac	1,075

Figure 9 - Split of Trips per Bridge Tunnel in 1990

This data indicates that in 1990, few drivers from Virginia Beach used the MMMBT (only 7% of the estimated trips). Thus, the primary route used in this report is obviously the preferred route for drivers on Route 44. This data also displays the lack of use of the MMBT, thus making it a good candidate for a secondary route. It is not congested and the trip takes little over twenty minutes longer. Drivers familiar with the area should be prone to divert to the secondary route if traveler information suggests a delay longer than twenty minutes.

CHAPTER 4 - DATA COLLECTION AND PRE-PROCESSING

Two different types of data were required for this report; dynamic message sign data and loop detector data. The DMS data was necessary to determine the times that each message was displayed by the Smart Traffic Center. Loop detector data was necessary to provide the volume of traffic at points in the interchange.

DYNAMIC MESSAGE SIGN DATA

The Smart Traffic Center in Hampton Roads was contacted to receive the DMS data. Unfortunately, due to software difficulties, data on the DMS system was not archived or stored in any capacity. This problem was solved after a visit to the Smart Traffic Center. After talking to several people it was determined that the operating times of the DMS system could be extrapolated from an archived incident database. The structure of the incident database included a field for 'incident type'. One of the possible incident types was 'tunnel'. This term referred to any incident in the HRBT. By searching the database, it was possible to determine when the DMS signs were used. The process consisted of querying the database under the 'tunnel' incident type and manually looking in the description of the incident when the DMS system was used.

Using this method, 249 incidents using the DMS system were found. These 249 incidents included the beginning and ending times of each incident and all took place between August 1998 and July 1999. All of these incidents used the "EXPECT DELAYS" message described in Chapter Three. There were too few "USE ALTERNATIVE ROUTE" messages used over the collection period to make a significant analysis.

After these 249 incidents were found, loop detector data archive in the Smart Travel Lab at the University of Virginia was processed and matched to these times.

LOOP DETECTOR DATA

The Smart Traffic Center in Hampton Roads sends its loop detector data to the Smart Travel Laboratory at the University of Virginia. Loop detector data for this project during the time period of August 1998 to July 1999 was accessed in the Smart Travel Laboratory.

For this report, traffic counts from the detectors was converted into volume per hour data using the software program Analyx (available in the Smart Travel Laboratory) and Microsoft Excel. Analyx is a program that queries the loop detector database as described by the user and creates a Microsoft Excel spreadsheet of the results. Loop detector data collected by the Smart Travel Laboratory is stored in two minute intervals. The spreadsheets were used to sum both the volume and the time interval data. These sums were used to calculate the volume per hour of each loop detector during the first hour after each incident. Thus, the data pre-processing of the detector data consisted of querying the detector database for all of the two-minute intervals from the time of the incident until an hour afterward. Then, the data was converted into volume per hour using Microsoft Excel.

DATA PROCESSING

Loop detector data was gathered for each of the 249 DMS time intervals. For each data point, loop detector data within the interchange studied were searched and volume per hour data extracted. To calculate the volume per hour the volume and collection times for the data were summed. Then, the volume was divided into the collection time and converted to volume per hour. Volume per hour was used instead of volume due to the variance in collection times for the loop detector data. In addition, this was also performed for four other times associated with the data point. These points were used to determine the average traffic characteristics of the interchange studied, when the DMS system was not displaying messages. The four points used were the same time of day two weeks before the incident, one week before the incident, one week after the incident and two weeks after the incident. Thus, each data point would have five separate days of information; the original date of the incident, as well as four related dates that could be averaged to determine the normal traffic of the interchange.

After processing some of the data, it was apparent that the quality of the loop detector data posed problems. The original plan involved processing volume data for six different detector groups; 19, 20, 196, 198, 200 and 201 as depicted in Figure 8. Unfortunately, groups 19 and 20 did not contribute any data during the August 1998 to July 1999 data collection period. Thus, only the mainline loop detector data and the off-ramps traveling north were used to determine the volume of travelers heading towards the HRBT. Unfortunately, the remaining detectors were not constantly functional. The 249 data points had to be narrowed down to 101 data points for which at least three of the four related dates good data. Another result of the poor loop detector data is a lack of data from May 1999 to July 1999. An example of the processed data is shown in Figure 10.

		(0-60 minutes after, in vehicles/hour)						
		Mainlines			**North Off-Ramps**			
BEGIN	**END**	**200**	**201**	**Total**	**196**	**198**	**Total**	**Percentage North**
2/23/99 16:01	2/23/99 17:15	2965	3019	5984	0	2350	2350	39.3
2/9	*2 weeks earlier*	2911	2969	5880	0	2431	2431	41.3
2/16	*1 week earlier*	2335	2420	4755	0	1932	1932	40.6
3/2	*1 week after*	3004	3049	6053	0	2434	2434	40.2
3/9	*2 weeks after*	2700	2748	5448	0	2198	2198	40.3

Figure 10 - Example of Processed Data

Figure 10 shows how the data was organized for this project. The original beginning and ending times for the incident appear at the top and the four related times are listed beneath the original information. The volume per hour data for the first hour after the beginning time of the incident is listed next to each date. This data was collected for each of the remaining operational loop detector groups (196, 198, 200 and 201). Finally, the percentage of the mainline traffic turning north at the interchange was calculated by summing the north off-ramp traffic and dividing by the mainline traffic.

POSSIBLE SOURCES OF ERROR

While collecting and processing the data, several possible sources of error were noted. Although some of these are mentioned above, all encountered sources of error are noted in the list below.

- *Number of related times used in analysis*

  In the main analysis of this report, the average percentage of traffic that traveled north during the related times was compared to the percentage that traveled north when the DMS was used. The percentage north for the related times should represent what the average percentage north for the interchange would have been had the DMS not been in use. Therefore, it was important to keep the time of day, day of week, and time of year constant. Since only four times were averaged, this may have resulted in a poor estimate of the 'average' traffic patterns for the interchange during the time in question.

- *Lack of direct DMS data*

  The DMS data was collected indirectly through an incident database. This might have led to problems in determining when the DMS system was used. Since the main purpose of the incident database is to archive incident information and not DMS information, some of the DMS information could have been incomplete or inaccurate. It is possible that the times of the incidents do not match up with the times the DMS system was used. According to the

Hampton Roads Smart Traffic Center, the time lag between reporting an incident and displaying a message on the DMS system is approximately three minutes. In addition, extrapolating about the DMS system's use from notes in the incident database could have introduced further error. Since there was no set method for entering this data, it is possible that the database could have been misinterpreted.

- *Quality of loop detector data*

  The quality of the loop detector data is an important factor in the quality of the results. If the volumes reported by the loop detector system in Hampton Roads were not accurate, the results of this report could vary drastically. Since it is clear that the loops sometimes fail to respond on a regular basis, the quality of the loop detector system is questionable. The failure to respond did cause large gaps in the data collected.

- *Use of one hour time interval*

  The volumes used in the analysis were calculated for the first hour after the message was displayed. This assumes that the effect of the message on drivers would take place within one hour. It is possible that the actual time until the DMS system diverts drivers may vary or lie outside the one-hour interval. A one-hour interval was chosen because the ending time of some incidents was close to one-hour after the beginning time. In addition, by varying the time interval during which the volumes were calculated, the data collection process would have been increased to a length infeasible for this project.

Three of these sources of error can be attributed to the quality of the data. The 'lack of direct DMS data' source of error would be eliminated though a quality source of DMS data. Improved loop detector data could increase the number of related times used in the analysis and decrease doubts in the reliability of the data. The remaining source of error, the use of the one-hour time interval, is due to the analysis methodology of this project.

CHAPTER 5 - DATA ANALYSIS AND RESULTS

After completing the data collection and processing described in the previous chapter, the data was analyzed to determine the effect of the DMS system on traveler behavior. The focus of the data analysis was the percentage north calculation.

DIVERSION PERCENTAGE ANALYSIS

The main analysis of this report compares the percentage north during times the DMS system was used versus the average percentage north during the related times when the DMS system was not used. The variable used for this comparison is called 'diversion percentage'. The diversion percentage for each of the 101 remaining data points (times the DMS system was used with available loop detector data) was calculated by averaging the three or four related times and then subtracting the percentage north for the time the DMS system was used. For example, the data presented in Figure 10 would lead to the results contained in Figure 11.

Example Calculation of Diversion Percentage	
Percentage North when DMS used	39.9%
Average Percentage North of similar times	40.6%
Diversion Percentage	1.3

Figure 11 - Example Diversion Percentage Calculation

The diversion percentage was calculated for each of the data points; these results are contained in Appendix A. The results and a statistical analysis of these results are contained in Figure 12.

Results of Diversion Percentage Analysis	
Count	101
Sum	2.7
Average	0.027
Standard Deviation	3.76
95% Confidence Interval	(-0.72, 0.77)

Figure 12 - Results of Diversion Percentage Analysis

DIVERSION PERCENTAGE RESULTS

The results of the diversion percentage analysis indicate that the DMS system does not affect driver behavior in the case studied in this report. This conclusion is supported by the low average diversion percentage (near zero) and the fact that the 95% confidence interval has both a positive and negative boundary. There are several possible explanations for this result.

- *The 'weak' message displayed on the DMS*

  The poor diversion percentage results found in this report could have been caused by lack of 'strength' in the message displayed to travelers. A quality traveler information system displays valuable information in a timely manner. The message used on the DMS system studied in this report said "I64 TUNNEL CONGESTED, EXPECT DELAYS". Although this message displays information to travelers quickly, it lacks the real information drivers need. Drivers are interested in the length of the delay and possible secondary routes they can choose. Although existing signs inform drivers of the MMBT, the DMS system does not. The primary deficiency of the message used is the lack of description of the delay. The particular message studied in this report was not designed to deviate large amounts of traffic from HRBT to MMBT, but a more forceful message is necessary to achieve even a slight deviation.

- *The distance from a secondary route*

  In the scenario studied in this report, it is quite possible that the secondary route (MMBT) was far enough away that drivers did not want to divert towards it. If this were the case, then drivers would need to have descriptive information explaining the length of the delay to determine if it would be worth the time necessary to deviate.

- *The unwillingness of drivers to divert*

    The message displayed in the DMS system was used often enough that drivers who commonly use the route studied would begin to ignore the messages displayed. This is due to the lack of 'strength' of the message displayed and the accuracy of the message displayed. If drivers constantly saw these messages several times a week, they would begin to become accustomed to the delay in the HRBT. These drivers probably had a tolerance for delay in HRBT because of the frequency of their occurrence. Hence, a sign with a 'weak' message would not convince enough drivers to divert. Until a message displayed on the sign was strong enough to be above the tolerance for delay already set by drivers, the amount of deviation would remain low.

It should be noted that these results are restricted to the strict boundaries of the scenario studied in this report. Other scenarios will have different factors that could change the diversion percentage results in a similar analysis, such as:

- *Location of DMS*

    The location of the DMS is factor for diversion the system will generate. It is the author's opinion that a driver needs to have a good line of sight to the sign, he or she needs to be able to read the sign clearly and understand its contents before making a decision. The sign also needs to be a proper distance from a decision-making location, like an interchange, so that a driver has enough time to decide on a secondary route.

Three dynamic message signs were spaced over the highway studied, between Virginia Beach and the I64 interchange. These signs all displayed the same message. In addition, static signs along Route 44 suggest using use MMBT as an alternative route to the HRBT.

- *Content of DMS*

The amount of diversion depends greatly on the content of the DMS system. Drivers require accurate and descriptive information in order to divert. As discovered in the literature review (Polydoropoulou et al. 1996), the message displayed needs to be timely and present pertinent information. It must to contain enough information about the situation for a driver to make a proper decision. For example, a sign displaying the message 'expect delays' is not as effective as a sign message reading 'expect 30 min delays'.

In the scenario studied, the content of the DMS system was not descriptive of the delays encountered. The lack of description of delay to the drivers probably led to a decrease in possible diversion. If the messages displayed contained more information about the delay, such as the time of the delay or the length of the backup, larger diversion percentages might have been observed.

- *Reliability of DMS*

The reliability of the DMS system studied is another important factor in the amount of diversion encountered in a scenario (Polydoropoulou et al. 1996, Levinson et al. 1999). The information on the sign needs to be reliable and the system needs to work properly for drivers to respect the information displayed.

In the scenario studied, the dynamic message signs worked properly during the year data was gathered. The technical problems encountered involved the reliability of the loop detectors, not the message signs.

- *Availability and quality of secondary route(s)*

For a driver to divert from a primary route, at least one quality secondary route must exist. A good DMS system makes recommendations on secondary routes available to travelers. These routes need to be easily accessible and have a travel time only slightly longer than the primary route.

The scenario in this report had definite primary and secondary routes. One of the objectives of the Hampton Roads Smart Traffic Center is to divert some traffic from the HRBT towards the MMBT. Static signs alert drivers to the existence of the secondary route before they reach the interchange studied. The secondary route is obvious to anyone familiar with the area. Tourists and visitors would not have difficulty understanding the secondary route since it is part of the highway system and is easy to understand on a map.

SENSITIVITY ANALYSES

The results contained more information than the average diversion percentage analysis. Data such as the time of day, the day of week, the total mainline volume and the time of year were also recorded as shown in Appendix A. These variables were used to perform sensitivity analyses on the diversion percentage. The objective of these analyses was to determine what effect each of these variables had on diversion percentage.

DAY OF WEEK SENSITIVITY ANALYSIS

To determine the effect the day of the week had on diversion percentage, the day of the week for each data point was recorded. Then after separating the data into seven different groups, the same statistical analysis was performed on each group. The results are displayed in Figure 13. Within Figure 13, *Count* refers to the sample size, *Mean* refers to the mean diversion percentage of the sample (the overall mean diversion percentage was 0.03), and *standard deviation* refers to the standard deviation of the sample.

Day of the Week Sensitivity Analysis			
Day of the Week	*Count*	*Mean*	*Confidence Interval*
Monday	15	-0.43	-2.86, 2.00
Tuesday	18	-1.64	-3.45, 0.16
Wednesday	19	0.03	-0.84, 0.90
Thursday	22	0.74	-0.73, 2.21
Friday	19	0.98	-0.80, 2.77
Saturday	0	---	---
Sunday	8	0.40	-5.06, 5.86

Figure 13 - Day of Week Sensitivity Analysis

TIME OF DAY SENSITIVITY ANALYSIS

The same sensitivity analysis approach was used to determine the effect of the time of day on diversion percentage. For this analysis the data points were split into four groups, AM-Peak (6:30 to 8:30 AM beginning times), PM-Peak (3:30 to 6:00 PM beginning times), Overnight (11:00 PM to 4:00 AM beginning time), and Off-Peak (all other times). The results are displayed in Figure 14.

Time of Day Sensitivity Analysis			
Time of Day	*Count*	*Mean*	*Confidence Interval*
AM-Peak	2	1.25	-17.17, 19.87
PM-Peak	38	-0.47	-1.37, 1.44
Overnight	4	-3.3	-11.48, 10.75
Off-Peak	57	0.51	-0.58, 1.64

Figure 14 - Time of Day Sensitivity Analysis

TIME OF YEAR SENSITIVITY ANALYSIS

The time of year might also have an impact on diversion percentage due to the amount of tourists and changing volumes on the highway network during the summer months. The same approach for the previous sensitivity analyses was used to determine this impact. Figure 15 displays the results of the sensitivity analysis. The summer months are July and August and the winter months are December, January and February. Figure 16 displays a chart of diversion percentage versus the time of year.

Time of Year Sensitivity Analysis			
Time of Year	*Count*	*Mean*	*Confidence Interval*
Summer Months	14	2.92	0.06, 4.18
Winter Months	34	0.25	-0.63, 1.31

Figure 15 - Time of Year Sensitivity Analysis

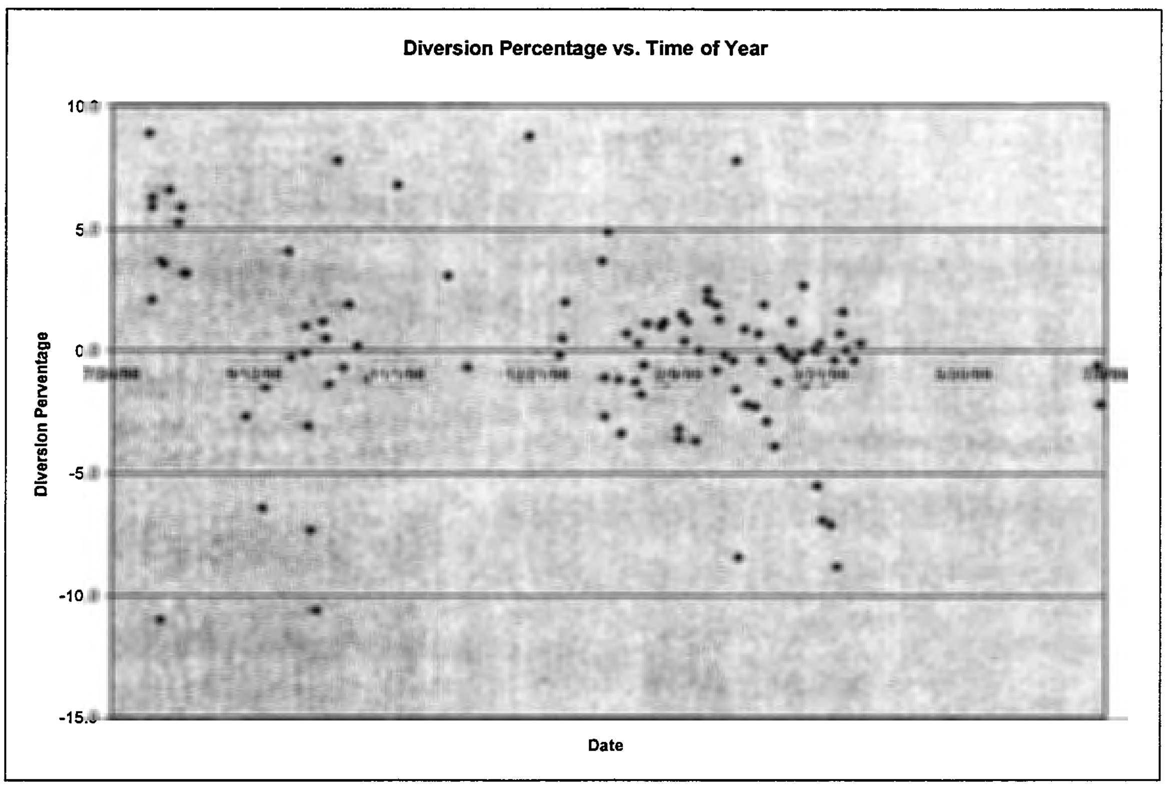

Figure 16 - Chart of Diversion Percentage vs. the Time of Year

MAINLINE VOLUME SENSITIVITY ANALYSIS

The final sensitivity analysis was performed was to compare the volume on the mainline highway approaching the interchange studied (Route 44) with the amount of diversion percentage. The results from this analysis should show if there is any link between low or high volumes and the amount of diversion. The results of this analysis are contained in Figure 17. For the purposes of this analysis, low volumes were considered to be less than 3,000 vehicles per hour, and high volumes were over 5,500 vehicles per hour.

Mainline Volume Sensitivity Analysis			
Volume	*Count*	*Mean*	*Confidence Interval*
Low	10	-2.27	-5.57, 4.75
Medium	35	-0.98	-2.43, 2.17
High	56	1.06	0.28, 1.17

Figure 17 - Mainline Volume Sensitivity Analysis

STATISTICAL TESTING OF SENSITIVITY ANALYSES

The data obtained from the sensitivity analysis appears to lead to several conclusions. Before these conclusions can be made, the data needs to be tested for its statistical significance. Due to the low sample sizes of the subset used in the sensitivity analyses, any conclusions drawn might be due to an inherent randomness in the sample rather than to any specific reason.

The statistical analysis performed was the Smith-Satterthwaite test. The Smith-Satterthwaite test, similar to the *t*-test, is best used when comparing two populations in which the variances are not assumed the same, which is the case under the *t*-test. The following sections outline the results of these tests on the sensitivity analyses. Within these figures, μ_1 is the diversion percentage for the first set of data and μ_2 is the diversion percentage for the second set of data. The degrees of freedom used for the t statistic is denoted as v, and the confidence interval used in the analysis (1-α) was 95%. This means that if the null hypothesis (H_o) is FALSE, then the alternative hypothesis (H_a) is TRUE. In this case, when the alternative hypothesis is true, then the sensitivity analysis results are statistically significant (the mean of the first sample is higher then the mean of the second sample) with a 95% degree of confidence (Devore 1995).

The Smith-Satterthwaite is used over the traditional *t*-test for two reasons. First, the variances of the populations cannot be assumed the same. The population variances are assumed different because the sample variances vary significantly. Second, the Smith-Satterthwaite test incurs less error when the sample sizes are different, as in the case with the sensitivity analysis performed (Devore 1995).

DAY OF WEEK SENSITIVITY ANALYSIS

This data tends to suggest that the diversion percentage increases on Thursdays and Fridays, as compared to earlier in the week. Before making these conclusions, a statistical analysis needs to be performed. As described above, the Smith-Satterthwaite test was used to determine the statistical significance of this analysis. The results of the test are displayed in Figure 18.

Day 1	Day 2	Ho	Ha	v	t'	t(0.05,v)	Ho?
Friday	Monday	$\mu1-\mu2=0$	$\mu1-\mu2>0$	28.9	2.02	1.7	FALSE
Friday	Tuesday	$\mu1-\mu2=0$	$\mu1-\mu2>0$	34.9	4.16	1.69	FALSE
Friday	Wednesday	$\mu1-\mu2=0$	$\mu1-\mu2>0$	32.2	1.76	1.69	FALSE
Thursday	Monday	$\mu1-\mu2=0$	$\mu1-\mu2>0$	27.3	1.76	1.7	FALSE
Thursday	Tuesday	$\mu1-\mu2=0$	$\mu1-\mu2>0$	35.7	4.01	1.69	FALSE
Thursday	Wednesday	$\mu1-\mu2=0$	$\mu1-\mu2>0$	38.1	1.43	1.69	TRUE
Friday	Thursday	$\mu1-\mu2=0$	$\mu1-\mu2>0$	37.4	0.41	1.69	TRUE

Figure 18 - Statistical Analysis of Day of Week Sensitivity Analysis

The results from these statistics prove, with 95% certainty, that Friday's diversion percentage is higher than Monday's, Tuesday's and Wednesday's. Thursday's diversion percentage is higher than Monday's and Tuesday's.

TIME OF DAY SENSITIVITY ANALYSIS

The Smith-Satterthwaite test was also used to determine the statistical certainty of these results, shown in Figure 19. AM-Peak and Overnight data was rejected because of the lack of data points. Thus, the analysis focused on comparing Off-peak to PM-Peak data.

Time 1	Time 2	Ho	Ha	v	t'	t(0.05,v)	Ho?
Off-Peak	PM-Peak	$\mu1-\mu2=0$	$\mu1-\mu2>0$	87.8	2.54	1.7	FALSE

Figure 19 - Statistical Analysis of Time of Day Sensitivity Analysis

The results of this statistical analysis show that the diversion percentage for Off-peak traffic is higher than the diversion percentage for PM-Peak traffic.

TIME OF YEAR SENSITIVITY ANALYSIS

The Smith-Satterthwaite test was used to test the validity of these results. These results are displayed in Figure 20 and show that the summer months have a statistically significant higher diversion percentage than the winter months.

Time 1	Time 2	Ho	Ha	v	t'	t(0.05,v)	Ho?
Summer	Winter	$\mu1-\mu2=0$	$\mu1-\mu2>0$	18.7	4.08	1.73	FALSE

Figure 20 - Statistical Analysis of Time of Year Sensitivity Analysis

MAINLINE VOLUME SENSITIVITY ANALYSIS

The Smith-Satterthwaite test was again used to determine the statistical validity of these results. The test was performed to determine if diversion percentage was actually higher during time of high volumes as compared to medium or low volumes. Figure 21 contains the results of these tests.

Volume 1	Volume 2	Ho	Ha	v	t'	t(0.05,v)	Ho?
High	Low	$\mu 1-\mu 2=0$	$\mu 1-\mu 2>0$	11.1	4.65	1.8	FALSE
High	Medium	$\mu 1-\mu 2=0$	$\mu 1-\mu 2>0$	62.4	4.91	1.67	FALSE

Figure 21 - Statistical Analysis of Mainline Volume Sensitivity Analysis

The results prove that under high mainline volumes, the diversion percentage increases.

SENSITIVITY ANALYSIS RESULTS

The results obtained from the four sensitivity analyses showed different trends in diversion. The conclusions reached from these analyses are presented below.

- *The day of the week affects the amount of diversion*

  The day of the week sensitivity analysis showed that some days had a statistically significant higher diversion percentage than other days of the week. Specifically, the diversion percentage on Fridays was higher than on Mondays, Tuesdays and Wednesdays. In addition, the diversion percentage on Thursdays was significantly higher than on both Mondays and Tuesdays.

  Each day from Monday until Friday showed more diversion percentage than the day before. Possible reasons for this deviation are: higher volumes encountered during Thursdays and Fridays, the tolerance against diversion lowered later in the week, and a shift in driving patterns from Monday to Friday.

- *More diversion occurs during Off Peak hours than PM Peak hours*

  The time of day sensitivity analysis performed in Chapter 5 resulted in one statistically significant result; the average diversion percentage during Off-peak times was higher than the average diversion percentage during the PM peak hours.

This result can be explained simply. Drivers during the PM peak differ from drivers during Off-peak. PM peak drivers are usually commuters travelling from work to home. These drivers are most likely to have a shorter trip length, which would create a high tolerance to diversion. They most likely would not divert because of a short delay since they are not travelling great enough distances to take the secondary route. For example, a tourist driving from Virginia Beach to Richmond would definitely divert more often than a commuter driving from one side of Hampton Roads to the other. In addition, drivers familiar with the DMS system are more likely to know if the system is reliable. The low amount of diversion might be due to drivers ignoring the signs, possible because they are inaccurate or have proved otherwise unreliable. This is another possible explanation why unfamiliar drivers would be more likely to divert than familiar drivers.

- *More diversion occurs during Summer months than Winter months*

The time of year sensitivity analysis resulted in one statistically significant result; the average diversion percentage during summer months was larger than the diversion percentage during winter months.

This result can be due to two factors. First, types of travelers generally found during the summer are different from those found in the winter. During summer, more tourists will be travelling across the Hampton Roads area. These drivers are familiar with the highway network and are more willing to deviate from a route because of their long trip lengths. These drivers are already expecting a long highway-based trip and are willing to take a secondary route to avoid delay. Commuters tend to have shorter trip lengths and their destination might lie close to the primary route, thus making them hesitant to take a secondary route. Second, traffic volumes are higher during the summer months. This creates a higher amount of delay and backup that could in turn create a higher diversion rate. Even if the amount of delay is constant between the two times of year, the higher traffic volumes create a sense of congestion that increases a driver's perception of possible delay.

- *High traffic volumes lead to higher diversion percentages*

The statistical analysis performed on the results of the mainline volume sensitivity analysis resulted in one main conclusion; higher volumes lead to more diversion. Of the three possible volume conditions, the high volume condition was the only one that resulted in a positive average diversion.

There are two possible explanations for this result. First, people's perception of congestion is higher under heavy mainline traffic. If drivers see a large number of cars on the road, they assume that the delay will be worse in the bridge tunnel and are more likely to divert. Drivers in low or normal traffic do not necessarily believe the sign or conceive that the delay will be very long. Second, drivers familiar with the area might encounter congestion in the bridge tunnel under low, normal and heavy traffic conditions. It is possible that the delay under heavy traffic conditions is generally longer than under other conditions. These drivers would then be more likely to divert when a message is displayed during heavy traffic conditions.

CHAPTER 6 - SECONDARY ANALYSES

Two secondary analyses were performed after the analyses described in Chapter 5. A decision to perform the first secondary analysis was based on a change made in the usage of the dynamic message signs by the Smart Traffic Center in Hampton Roads. Secondary Analysis II is a diversion analysis using an alternate analysis methodology than described in Chapters 4 and 5.

SECONDARY ANALYSIS I

SCENARIO DESCRIPTION

During the course of this project, the Hampton Roads Smart Traffic Center altered the times messages on the DMS system were displayed. For the data analyzed in Chapter 5, the message displayed was "I64 TUNNEL CONGESTED/ EXPECT DELAYS" and was used in times when the delay was under 30 minutes. The Smart Traffic Center determined that this message sign was ineffective, as demonstrated in the previous chapter. A decision was made to use the DMS system only to divert drivers toward the MMBT when a 30-minute or longer delay existed. Starting in September 1999, the DMS system was not used to alert drivers of delays under 30 minutes, although a message about the delay was broadcast on highway advisory radio. When the delay in the HRBT was longer than 30-minutes, the following message was displayed on the three signs studied in this report: "I64 TUNNEL BLOCKED/ USE ALTERNATE ROUTE".

A secondary analysis was performed on a small amount of data collected after this change was instituted. The previous analysis described earlier in this report will be referred to as the primary analysis. The first secondary analysis was performed in the same manner as the primary analysis. First, the data was collected and processed as described in Chapter 4. For the secondary analysis, a search through the incident database recovered nine times when the DMS was used between September 1999 and December 1999 (compared to 249 in the primary analysis). Due to gaps in the loop detector data, the number of data points decreased to seven (compared to 101 in the primary analysis). Next, the same diversion percentage analysis described in Chapter 5 was performed on the new data.

DIVERSION PERCENTAGE ANALYSIS

The main purpose of the secondary analysis is to determine if the diversion percentage of the new data (September to December 1999) was higher then the diversion percentage of the original data (August 1998 to July 1999). Of the seven data points, five had positive diversion percentages and the mean diversion percentage was larger. The results are contained in Figure 22.

Results of Diversion Percentage Analysis	
Count	7
Sum	8.4
Average	1.2
Standard Deviation	3.76
95% Confidence Interval	(-2.27, 4.68)

Figure 22 - Results of Secondary Diversion Percentage Analysis

RESULTS

At first glance, it appears that the new message system diverts more drivers. The higher average diversion percentage could be misleading due to the relatively low number of data points. This can be seen in the confidence interval, which contains ranges both higher and lower than the confidence interval for the primary analysis. To determine if the average diversion percentage from secondary analysis I is actually higher than the diversion percentage from the primary analysis, statistical testing is necessary.

Unlike the statistical analysis performed in chapter 5, the Smith-Satterthwaite test was not used. This is because the standard deviation and variances of the primary and secondary diversion percentage analyses were nearly identical. If it can be assumed that the variances of the two populations are equal, than the *standard t-test* could be employed. The results of this test are displayed in Figure 23.

Analysis 1	Analysis 2	Ho	Ha	t	t(0.05,106)	Ho?
Secondary	Primary	$\mu1-\mu2=0$	$\mu1-\mu2>0$	0.21	1.66	TRUE

Figure 23 - Statistical Testing of Secondary Analysis

The results of the statistical testing prove that the difference in average diversion percentages is not statistically significant. This is due to the low amount of data points, the variance within the data and the small difference in average diversion percentage.

Two conclusions can be drawn from secondary analysis I. First, the change in the usage of the DMS system appears to be beneficial. Recent data suggests that an increase in diversion percentage has occurred. Second, this change is not statistically significant. Thus, it might be too early to determine the effectiveness of the new messages compared to that of the original messages.

SECONDARY ANALYSIS II

SCENARIO DESCRIPTION

Various sources of error for this project are presented at the end of Chapter 4. The only error attributed to engineering judgement was the use of the one-hour time interval in the analysis methodology. After performing the primary analysis (Chapter 5), a decision was made to perform another diversion analysis on a sub-set of the data. This analysis, the second secondary analysis, was performed to test a slightly different analysis methodology. The purpose of this analysis is to compare two different methods of calculating diversion.

The second secondary analysis uses times before and after (on the same day) the DMS system was used to determine the amount of diversion. The primary analysis used three or four times when the DMS system was not used for comparison, as described in Chapter 4. For the second secondary analysis, a vehicles per hour calculation was performed for three time intervals; 10 minutes before a message was displayed, 5 to 15 minutes after, and 15 to 25 minutes after. The data used in this analysis was the 14 times the DMS system was used during the summer months. The second time period starts 5 minutes after the message is displayed because of the delay time in recording the beginning time of an incident in the database and the time messages appear on the signs. Calculation of the vehicles per hour was performed as described in Chapter 4. An example of one data point for the second secondary analysis is presented in Figure 24.

Example of Data used in Secondary Analysis II								
		(Volume, in vehicles per hour)						
BEGIN	**END**	**Mainlines**			**North Off-Ramp**			**Percentage North**
		200	**201**	**Total**	**196**	**198**	**Total**	
8/6/98 10:15	8/6/98 12:30							
	10:05 to 10:15	3979	2130	6109	149	1921	2070	33.9
	10:20 to 10:30	5142	3204	8346	120	1769	1889	22.6
	10:30 to 10:40	4172	2336	6508	125	1964	2089	32.1

Figure 24 - Example of Data used in Secondary Analysis II

DIVERSION ANALYSIS

The results of the second secondary analysis are presented in Figure 25. Included are the percentage north calculations for each of the three time-periods, the difference in percentage north for the time intervals after the message was displayed and the time interval before, and the diversion percentage from the primary analysis for the same data point.

Due to the abnormally large percentage north for the third time-period on the 6th data point, it is discarded from the remaining analysis. Of the thirteen remaining data points the average difference in percentage north between the first and second time periods is 1.6 (95% confidence interval -0.91, 4.06).

Results of Secondary Analysis II								
Number	Date	Begin	*Percentage North*			*Difference from 0-10 min before*		Diversion % from
			0-10 min.before	5-15 min. after	15-25 min.after	5-15 min. after	10-25 min. after	Primary Analysis
1	8/6/98	10:15	33.9	22.6	32.1	11.3	1.8	8.9
2	8/7/98	10:00	32.4	35.7	34.0	-3.3	-1.6	5.9
3	8/7/98	15:40	28.1	26.6	27.3	1.5	0.8	2.1
4	8/7/98	18:26	30.2	28.7	25.5	1.5	4.7	6.3
5	8/10/98	9:48	36.4	32.6	31.2	3.8	5.2	3.7
6	8/10/98	0:13	38.2	36.1	80.0	2.1	-41.8	-11.0
7	8/11/98	16:52	29.4	27.9	29.2	1.5	0.2	3.6
8	8/13/98	14:34	22.4	17.2	27.1	5.2	-4.7	6.6
9	8/16/98	0:52	32.7	34.5	38.9	-1.8	-6.2	5.3
10	8/17/98	14:24	27.8	30.1	29.7	-2.3	-1.9	5.9
11	8/18/98	16:22	31.5	32.1	29.2	-0.6	2.3	3.2
12	8/19/98	15:16	33.1	31.8	27.5	1.3	5.6	3.2
13	7/6/99	14:00	41.8	36.4	37.5	5.4	4.3	-0.6
14	7/7/99	14:30	42.6	45.6	41.4	-3.0	1.2	-2.2

Figure 25 - Results of Secondary Analysis II

The average difference in percentage north between the first and third time-periods is 0.9 (95% confidence interval -1.34, 3.15). The average diversion percentage from the primary analysis is 4.0 (95% confidence interval 2.17, 5.82)

RESULTS

The results of the second secondary analysis suggest that diversion is occurring during five to twenty-five minutes after the message is displayed. The average difference in the percentage of vehicles turning towards the HRBT decreases after the messages are displayed. This decrease is relatively small and, as the confidence intervals suggest, could range anywhere from a higher amount of diversion to a negative amount of diversion. Due to the range of the confidence intervals, a clear conclusion to the amount of diversion caused by the messages cannot be made. Even at the extreme limits of the confidence intervals, the possible amount of diversion is relatively small. This result is similar to the result from the primary analysis.

The difference in diversion from the second to third time intervals suggests that more diversion occurs in the first minutes the sign is displayed compared to fifteen to twenty-five minutes later. Unfortunately, due to the variance within the data it cannot be concluded that the actual mean for the second interval is higher than the mean for the third interval.

When each data point is examined, the results of the secondary analysis differ from the primary analysis. Although some data points from both analyses have similar results (numbers 1, 3, 4 5, 7, 12), several differ greatly (numbers 9 and 10). Due to the disagreement on the amount of diversion caused by the DMS system for each data point, it is difficult to conclude that both analysis methodologies agree. Both show a slight amount of diversion for the summer months, but a breakdown of the data finds many discrepancies within the two sets. A possible explanation for this is the variance within traffic volumes. Variance within traffic volumes could skew the vehicles per hour counts enough to 'cloud' the results. This would explain the large confidence intervals for the data. Thus, the conclusion that a slight diversion occurs during the summer months could be correct, but determining an exact average diversion rate is difficult, using either method of analysis, due to the variance within the data.

CHAPTER 7 - CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF CONCLUSIONS

This project attempted to determine the effect of the DMS in changing drivers' route selection in the Hampton Roads area of Virginia. The route choice studied was the decision between the Hampton Roads Bridge Tunnel (HRBT) and the Monitor Merrimac Bridge Tunnel (MMBT) when travelling from Virginia Beach across the James River. A DMS system is used by the Hampton Roads Smart Traffic Center in an attempt to switch drivers from the HRBT to the MMBT when the HRBT is congested.

The results from this project indicate that the DMS system does not divert drivers away from the HRBT. The calculations show that the average amount of people choosing to turn towards the HRBT instead of the MMBT did not change when the DMS system was used. The lack of driver deviation could be due to several reasons. First, the message displayed on the DMS system was vague and contained little information. The secondary route of the MMBT is over twenty minutes longer. Thus, drivers would require quantitative information about the delay in the HRBT to deviate from their route. In addition, the length of the secondary route and the unwillingness of drivers to divert might have contributed to the low amount of diversion.

The sensitivity analyses performed uncovered some interesting patterns in diversion under different conditions. It was determined that the day of the week, the time of year, the amount of traffic on the highway and the time of day all effect the amount of diversion. More drivers diverted on Thursdays and Fridays, during summer months compared to winter months, when the highway was crowded and during off-peak times.

The usage of the DMS system was changed in September 1999. A secondary analysis on data collected after this change suggests that an increase in diversion percentage might have occurred. This cannot be proved due to the low amount of data points and the variance within the data. In addition, a second secondary analysis was performed using a different analysis methodology. This analysis compared the traffic volumes from three time intervals, one before and two after, the message was displayed. The results from the second secondary analysis agreed on average with the primary analysis, but when looked at in detail, discrepancies in the two sets of results were found. This suggests that although both methods might conclude that a small amount of diversion exists, neither can predict the actual amount accurately due to fluctuations in general traffic flow.

RECOMMENDATIONS

The results from this project found that although the DMS system was used to divert drivers towards the MMBT, the amount of drivers diverting was minimal. Several changes could be made to the DMS system in an effort to increase the amount of diversion.

- *Improved messages*

  As stated in the review of relevant literature, research has been performed concluding that drivers prefer specific quantitative delay information. The messages displayed on the DMS system studied in this report did not display quantitative delay information. An improvement to the DMS system could include displaying the length of the delay on the HRBT. Drivers are more likely to deviate from their route when they can make well-informed decisions.

- *Use DMS system only under significant delay*

  If the extra time to travel through the MMBT is twenty minutes, then the DMS system should only be used to divert drivers when the delay encountered in the HRBT is longer than twenty minutes. It is recommended that the DMS system only be used to divert drivers when at least a thirty-minute delay exists within the HRBT and this information could be displayed on the DMS system.

In September 1999, the Hampton Roads Smart Traffic Center ceased displaying messages when the estimated delay was under 30-minutes. The secondary analysis performed in Chapter 6 indicates that this change might have increased the average diversion percentage.

- *Improve archiving system*

  Data from the DMS system should be recorded and archived. If there were a database of messages displayed, and the times they were displayed, analyses similar to this project would be easier to perform. In addition, any applications or models for the DMS system would then have a reliable source of data.

AREAS OF FUTURE RESEARCH

Several research areas could expand upon the research conducted in this project. These research areas could add to the understanding of driver behavior and en-route traveler information or could create applications to help transportation officials.

- *Conduct similar analysis on additional sites*

  Although the results from this project that the DMS system caused only minimal diversion, there are other potential sites to analyze within the Hampton Roads area. The DMS system is used to divert drivers in other situations; most notably, the opposite crossing of the James River from the peninsula side of Hampton Roads to the southern side. The scenarios studied can also be selected from sites outside the Hampton Roads area, as long as the necessary data is available. The same analysis methodology that was used in this report can be applied to these additional sites, thus providing a level comparison of the diversion at two separate sites.

- *Follow up sensitivity analysis conclusions*

  The conclusions derived from the sensitivity analysis are limited to the scenario studied in this project. More research could be performed to determine how driver behavior is affected by variables studied (time of day, day of week, time of year and traffic volume). This research would attempt to determine if drivers encountering any general en-route traveler information would respond with the same tendencies as those discovered in this project.

- *Follow up secondary analysis*

  The secondary analysis suggested that the overall diversion percentage has increased due to the changes made in the usage of the DMS system. The secondary analysis could not prove this statistically because it lacked the proper amount of data. More research could be performed in the future to determine if the changes made in September 1999 has a significant impact in the amount of diversion.

- *Formulation of prediction models*

  The data processed in this project could be used in the formulation of a prediction model. Future research could create a model that takes the database used in this project and predicts an expected amount of diversion. Variables such as the beginning time of the message, the volume on the road, the type of message displayed, the time of year, the time of day and the day of the week could be used as model inputs. The output of the model would be an estimated diversion percentage to expect for the hour after the message is first displayed.

This prediction model could be used to estimate the amount of traffic diverting to the secondary route in real-time. If the data inputs could be received quickly, a model could immediately predict the amount of diversion so that transportation officials could better operate the highway system. This might be necessary if officials want to know the expected volume change on the secondary route.

APPENDI X A - DIVERSION PERCENTAGE RESULTS

Number	Date of Incident	Percentage of Travelers Going North	Average Percentage of Travelers Going North at Similar Times	Number of Similar Times Used	Time of Day (AM Peak, PM-Peak, Off-Peak, Overnight)	Volume Type (Low, Medium, High)	Day of Week	Decrease in Percentage North During DMS Usage
1	8/6/98	31.9	40.8	3	Off-Peak	High	Thursday	8.9
2	8/7/98	32.1	38.0	4	Off-Peak	High	Friday	5.9
3	8/7/98	27.8	29.9	4	PM-Peak	High	Friday	2.1
4	8/7/98	27.6	33.9	4	Off-Peak	High	Friday	6.3
5	8/10/98	34.1	37.8	3	Off-Peak	High	Monday	3.7
6	8/10/98	61.5	50.5	3	Overnight	Low	Monday	-11.0
7	8/11/98	29.7	33.3	3	PM-Peak	High	Tuesday	3.6
8	8/13/98	26.4	33.0	3	Off-Peak	High	Thursday	6.6
9	8/16/98	37.5	42.8	3	Off-Peak	High	Sunday	5.3
10	8/17/98	29.0	34.9	3	Off-Peak	High	Monday	5.9
11	8/18/98	29.8	33.0	3	PM-Peak	High	Tuesday	3.2
12	8/19/98	29.6	32.8	3	Off-Peak	High	Wednesday	3.2
13	9/9/98	45.7	43.0	3	PM-Peak	High	Wednesday	-2.7
14	9/15/98	47.6	41.2	3	Off-Peak	Medium	Tuesday	-6.4
15	9/16/98	42.9	41.4	3	PM-Peak	High	Wednesday	-1.5
16	9/24/98	35.2	39.3	4	Off-Peak	High	Thursday	4.1
17	9/25/98	45.0	44.7	3	Off-Peak	Medium	Friday	-0.3
18	9/30/98	42.6	42.5	4	PM-Peak	High	Wednesday	-0.1
19	9/30/98	44.5	45.5	3	Off-Peak	Low	Wednesday	1.0
20	10/1/98	46.5	43.4	4	Off-Peak	Medium	Thursday	-3.1
21	10/2/98	47.6	40.3	4	PM-Peak	Medium	Friday	-7.3
22	10/4/98	55.2	44.6	4	Off-Peak	Low	Sunday	-10.6
23	10/6/98	39.9	41.1	3	PM-Peak	High	Tuesday	1.2
24	10/7/98	45.4	45.9	3	Off-Peak	Medium	Wednesday	0.5
25	10/8/98	45.2	43.8	4	Off-Peak	Medium	Thursday	-1.4
26	10/11/98	43.3	51.1	3	Off-Peak	Medium	Sunday	7.8
27	10/13/98	39.2	38.5	3	PM-Peak	High	Tuesday	-0.7
28	10/15/98	42.0	43.9	4	PM-Peak	High	Thursday	1.9
29	10/18/98	50.6	50.8	3	Off-Peak	Low	Sunday	0.2
30	10/22/98	39.2	38.0	3	PM-Peak	High	Thursday	-1.2
31	11/1/98	42.4	49.2	3	Off-Peak	Medium	Sunday	6.8
32	11/19/98	40.9	44.0	3	Off-Peak	Medium	Thursday	3.1
33	11/26/98	48.1	47.4	4	Overnight	Low	Thursday	-0.7
34	12/17/98	40.7	39.6	3	Off-Peak	Medium	Thursday	-1.1
35	12/18/98	41.0	49.8	4	Off-Peak	Medium	Friday	8.8
36	12/29/98	37.7	37.5	4	AM-Peak	Medium	Tuesday	-0.2
37	12/30/98	41.9	42.4	3	PM-Peak	High	Wednesday	0.5
38	12/31/98	38.7	40.7	3	Off-Peak	Medium	Thursday	2.0
39	1/13/99	39.2	42.9	3	PM-Peak	High	Wednesday	3.7
40	1/14/99	52.9	51.8	3	Overnight	Low	Thursday	-1.1
41	1/14/99	43.9	41.2	3	PM-Peak	High	Thursday	-2.7
42	1/15/99	40.6	45.5	3	Off-Peak	High	Friday	4.9
43	1/19/99	42.8	41.6	4	Off-Peak	Medium	Tuesday	-1.2
44	1/20/99	43.7	40.3	3	PM-Peak	High	Wednesday	-3.4
45	1/22/99	40.2	40.9	3	Off-Peak	High	Friday	0.7
46	1/25/99	42.2	40.9	3	PM-Peak	High	Monday	-1.3
47	1/26/99	38.7	39.0	3	Off-Peak	High	Tuesday	0.3
48	1/27/99	42.8	41.0	4	PM-Peak	High	Wednesday	-1.8
49	1/28/99	41.4	40.8	3	PM-Peak	High	Thursday	-0.6

50	1/29/99	40.1	41.2	4	Off-Peak	Medium	Friday	1.1
51	2/3/99	42.1	43.1	4	Off-Peak	High	Wednesday	1.0
52	2/4/99	40.3	41.5	4	Off-Peak	Medium	Thursday	1.2
53	2/5/99	41.0	39.7	3	Off-Peak	High	Friday	-1.3
54	2/9/99	43.0	39.8	4	PM-Peak	High	Tuesday	-3.2
55	2/9/99	48.2	44.6	4	Off-Peak	Medium	Tuesday	-3.6
56	2/10/99	40.5	42.0	3	PM-Peak	High	Wednesday	1.5
57	2/11/99	41.1	41.5	4	PM-Peak	High	Thursday	0.4
58	2/12/99	40.2	41.4	4	Off-Peak	Medium	Friday	1.2
59	2/15/99	40.6	36.9	4	Off-Peak	Medium	Monday	-3.7
60	2/16/99	40.5	40.5	4	PM-Peak	Medium	Tuesday	0.0
61	2/19/99	39.7	41.8	4	Off-Peak	Medium	Friday	2.1
62	2/19/99	38.6	41.1	3	Off-Peak	High	Friday	2.5
63	2/22/99	40.4	39.6	4	PM-Peak	High	Monday	-0.8
64	2/22/99	44.2	46.1	4	Off-Peak	Low	Monday	1.9
65	2/23/99	39.3	40.6	4	PM-Peak	High	Tuesday	1.3
66	2/25/99	40.6	40.4	4	PM-Peak	High	Thursday	-0.2
67	2/28/99	48.2	47.8	4	Overnight	Low	Sunday	-0.4
68	3/1/99	33.5	41.3	4	PM-Peak	High	Monday	7.8
69	3/1/99	48.1	46.5	4	Off-Peak	Low	Monday	-1.6
70	3/2/99	48.3	39.9	4	PM-Peak	Medium	Tuesday	-8.4
71	3/4/99	40.4	41.3	4	PM-Peak	High	Thursday	0.9
72	3/5/99	42.0	39.8	4	PM-Peak	High	Friday	-2.2
73	3/8/99	39.7	37.4	4	Off-Peak	High	Monday	-2.3
74	3/9/99	40.2	40.9	4	Off-Peak	High	Tuesday	0.7
75	3/10/99	40.9	40.5	3	PM-Peak	High	Wednesday	-0.4
76	3/11/99	39.9	41.8	4	PM-Peak	High	Thursday	1.9
77	3/12/99	42.0	39.1	4	Off-Peak	High	Friday	-2.9
78	3/15/99	41.8	37.9	4	Off-Peak	Medium	Monday	-3.9
79	3/16/99	42.8	41.5	4	PM-Peak	High	Tuesday	-1.3
80	3/17/99	42.2	42.3	4	Off-Peak	High	Wednesday	0.1
81	3/19/99	40.3	40.1	4	Off-Peak	High	Friday	-0.2
82	3/21/99	45.8	47.0	4	Off-Peak	Medium	Sunday	1.2
83	3/22/99	41.1	40.7	4	PM-Peak	High	Monday	-0.4
84	3/24/99	40.0	39.9	4	PM-Peak	High	Wednesday	-0.1
85	3/25/99	37.2	39.9	4	AM-Peak	High	Thursday	2.7
86	3/26/99	41.1	39.7	4	Off-Peak	Medium	Friday	-1.4
87	3/29/99	40.9	40.9	4	PM-Peak	High	Monday	0.0
88	3/30/99	46.3	40.8	4	PM-Peak	Medium	Tuesday	-5.5
89	3/31/99	41.6	41.9	4	Off-Peak	Medium	Wednesday	0.3
90	4/1/99	48.6	41.7	4	Off-Peak	Medium	Thursday	-6.9
91	4/2/99	41.9	40.6	4	Off-Peak	Medium	Friday	-1.3
92	4/4/99	55.0	47.9	4	Off-Peak	Medium	Sunday	-7.1
93	4/5/99	41.8	41.4	4	Off-Peak	Medium	Monday	-0.4
94	4/6/99	39.9	31.1	4	Off-Peak	Medium	Tuesday	-8.8
95	4/7/99	44.2	44.9	4	Off-Peak	Medium	Wednesday	0.7
96	4/8/99	45.9	47.5	3	Off-Peak	Medium	Thursday	1.6
97	4/9/99	40.3	40.3	3	PM-Peak	High	Friday	0.0
98	4/12/99	46.5	46.1	3	Off-Peak	Low	Monday	-0.4
99	4/14/99	40.0	40.3	3	PM-Peak	High	Wednesday	0.3
100	7/6/99	41.4	40.8	3	Off-Peak	Medium	Tuesday	-0.6
101	7/7/99	43.2	41.0	3	Off-Peak	High	Wednesday	-2.2

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