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research report

Evaluation of Driver Reactions for Effective Use of Dynamic Message Signs in Richmond, Virginia

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Dynamic message signs (DMS) are used in conjunction with other media to communicate traffic conditions, general information, and recommended diversion strategies to motorists. Previous studies using loop detector data to estimate diversion rates attributable to advisory messages on DMS have found that diversion is minimal when vague messages are displayed or a distant alternate route is the only option. For motorists traveling on I-95 through Richmond in the Virginia Department of Transportation's Central Region, however, when DMS alert motorists of incidents, I-295 serves as a comparable alternate route, adding no significant travel time to through trips. This scenario provides the opportunity to evaluate the effectiveness of DMS in traffic diversion without the major concerns of added trip time and the quality of the route.

This study investigated the impacts of existing message strategies to determine messages that maximize diversion for specific circumstances and to develop new messages for future deployment. An analysis was done for various message types and split into two diversion scenarios: (1) an incident on the primary freeway, I-95, encourages diversion of I-95 traffic to an alternate route, I-295; and (2) an incident on an intersecting freeway, I-295, encourages exiting I-295 traffic to remain on I-95 as an alternate route. The results showed trends where the use of particular words in messages is more effective than the use of others in achieving diversion when percentage of diverted traffic was used as the performance measure.

The effects on traffic flow by drivers' reactions to non-traffic messages were also investigated. Transportation agencies are frequently asked to post public service announcements on DMS when they are not being used for traffic-related purposes. It has been suggested that these messages are a distraction to drivers and result in queuing, creating mobility and safety hazards. An analysis that used speed as the performance measure showed minimal impacts on traffic flow from the display of non-traffic messages during weekday non-peak hours.

The study recommends that (1) travel time estimates for both the primary and alternate routes or the length or time of the delay be provided on DMS; (2) specific wording, as noted in the text, be used to induce diversion or simply to provide information; (3) messages be displayed in "title case" instead of "ALL CAPS" (i.e., all letters in a word are capitalized) for low-frequency messages; and (4) left-justified or "staircase" messages be used. Further, non-traffic messages should be one-phase messages and should be displayed only during non-peak periods to minimize the potential for queuing.

If the recommendations of this research are implemented, the enhanced effectiveness of diversion strategies will result in reductions of delay, fuel consumption, and emissions, as well as the potential for secondary accidents created by major incidents and other traffic flow disruptions. In 2007, the cost of delay for motorists in Richmond, Virginia, resulting from incidents was estimated at $119 million. A modest 1 percent reduction in this cost attributable to better diversion strategies that use DMS more effectively would result in an annual cost savings to VDOT of more than $1 million.

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FINAL REPORT

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ABSTRACT

Dynamic message signs (DMS) are used in conjunction with other media to communicate traffic conditions, general information, and recommended diversion strategies to motorists. Previous studies using loop detector data to estimate diversion rates attributable to advisory messages on DMS have found that diversion is minimal when vague messages are displayed or a distant alternate route is the only option. For motorists traveling on I-95 through Richmond in the Virginia Department of Transportation's Central Region, however, when DMS alert motorists of incidents, I-295 serves as a comparable alternate route, adding no significant travel time to through trips. This scenario provides the opportunity to evaluate the effectiveness of DMS in traffic diversion without the major concerns of added trip time and the quality of the route.

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The effects on traffic flow by drivers' reactions to non-traffic messages were also investigated. Transportation agencies are frequently asked to post public service announcements on DMS when they are not being used for traffic-related purposes. It has been suggested that these messages are a distraction to drivers and result in queuing, creating mobility and safety hazards. An analysis that used speed as the performance measure showed minimal impacts on traffic flow from the display of non-traffic messages during weekday non-peak hours.

The study recommends that (1) travel time estimates for both the primary and alternate routes or the length or time of the delay be provided on DMS; (2) specific wording, as noted in the text, be used to induce diversion or simply to provide information; (3) messages be displayed in "title case" instead of "ALL CAPS" (i.e., all letters in a word are capitalized) for low-frequency messages; and (4) left-justified or "staircase" messages be used. Further, non-traffic messages should be one-phase messages and should be displayed only during non-peak periods to minimize the potential for queuing.

If the recommendations of this research are implemented, the enhanced effectiveness of diversion strategies will result in reductions of delay, fuel consumption, and emissions, as well as the potential for secondary accidents created by major incidents and other traffic flow disruptions. In 2007, the cost of delay for motorists in Richmond, Virginia, resulting from incidents was estimated at $119 million. A modest 1 percent reduction in this cost attributable to better diversion strategies that use DMS more effectively would result in an annual cost savings to VDOT of more than $1 million.

FINAL REPORT

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INTRODUCTION

Dynamic message signs (DMS) are used in conjunction with other media to communicate traffic conditions, general information, and recommended diversion strategies to motorists. Some studies have used loop detector data to estimate diversion rates attributable to advisory messages placed on DMS, as well as travel time savings and safety impacts. Such studies have found that diversion is minimal when vague DMS messages are displayed or a distant alternate route is the only option.[1] But given a comparable alternate route and specific information on the DMS, particularly regarding incidents, diversion can be significant.[2] Driver responses to DMS are unpredictable, and any assumptions made for analysis require later validation.[3] Other studies have relied on costly and potentially inaccurate driver surveys to quantify driver acceptance of diversions recommended on DMS.[4,5] In addition, there are no documented reports of the impacts to traffic of general non-traffic alert messages shown on DMS, such as ozone conditions, future road work, etc.

At the north and south junctions of I-95 and I-295 in the Virginia Department of Transportation's Central Region, DMS are used to alert motorists of traffic blockages attributable to incidents on I-95 and I-295 and recommend diversion strategies to keep traffic flowing and reduce delays. For drivers traveling on I-95 through Richmond, an interstate highway, I-295, is available as a comparable alternate route that does not add significant travel time to through trips, adding only 5 mi to a 40-mi route. This scenario provided the opportunity to evaluate the effectiveness of DMS in traffic diversion without the major concerns of added trip time and the quality of the route.

PROBLEM STATEMENT

The recommendations for traffic diversion strategies using DMS are typically based on assumed travel behavior. Driver reactions (diversions) vary depending on the message that is shown on the DMS, and, in some instances, complex or confusing messages may add to rather than alleviate congestion.[6,7] The impacts of various message strategies need to be investigated to determine which messages maximize diversion for specific circumstances.

The effects on traffic flow of drivers' reactions to non-traffic messages also merited examination. Transportation agencies are frequently asked to post public service announcements on DMS when they are not being used for traffic-related purposes. The Richmond Traffic Operations Center (TOC) has received comments from motorists regarding the posting of non-traffic messages and safety messages.[8] It is possible that these messages may be a distraction to drivers and result in queuing, creating mobility and safety hazards, but no studies have verified this assertion.

PURPOSE AND SCOPE

The purpose of this study was to investigate the impacts of existing message strategies to determine messages that maximize diversion for specific circumstances and to develop new messages for future deployment. The investigation focused on methods that could be implemented to improve the effectiveness of the DMS network in Richmond, Virginia, between the north and south junctions of I-95 and I-295. An analysis was done for various message types and split into two diversion scenarios: (1) an incident on the primary freeway, I-95, encourages diversion of I-95 traffic to an alternate route, I-295; and (2) an incident on an intersecting freeway, I-295, encourages exiting I-295 traffic to remain on I-95 as an alternate route.

The effects on traffic flow by drivers' reactions to non-traffic messages were also investigated. Transportation agencies are frequently asked to post public service announcements, such as "CLICK IT OR TICKET," or announcements concerning upcoming events on DMS when they are not being used for traffic-related purposes. It has been suggested that these messages may be a distraction to drivers and result in slow-downs and the potential for queuing, creating mobility and safety hazards.[13,14] This study used speed detection equipment to track changes in speed as motorists approached a DMS with a non-traffic message.

METHODS

Six tasks were conducted to achieve the study objectives:

1. A literature review was conducted.
2. DMS locations in the study area were strategically selected.
3. Performance measures were selected.
4. A data collection plan was developed and executed.

5. The data were analyzed to meet the study objectives.

6. Results of the study were analyzed, and appropriate recommendations to enhance diversion strategies were made.

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Literature Review

The literature on traffic diversion strategies, DMS messaging techniques and guidelines, diversion and other behaviors of motorists in response to DMS, and other related factors was examined. The state of practice with regard to the use of DMS and the resulting traffic diversion in the United States and internationally were documented. The literature was identified through the use of TRIS, Worldcat, TLcat, and the University of Virginia Engineering Library databases.

Selection of DMS Locations

The north and south intersections of I-95 and I-295 in Richmond and major connected roads were selected with the assistance of the VDOT Central Regional Office to provide the network for the diversion analysis conducted in this study (Figure 1). Most count stations are located in the northern area of the Richmond region; thus, data from traffic entering the area on I-95 southbound were used to study diversion rates when recommended by DMS messages. Two DMS, DMS 8 and DMS 5 at mile markers 94.3 and 89, respectively, are upstream of I-295 on I-95 southbound at mile marker 84. Count station No. 12043 is located before I-295 at mile marker 85.4 on I-95 southbound and provides accurate counts of traffic entering the region. Count station No. 12042 is located at mile marker 85.1 on I-95 southbound, immediately after the ramp to I-295 South and before the ramp to I-295 North and merging ramps from I-295 North and South. Thus, the difference in traffic volumes between count stations No. 12043 and No. 12042 gives the volume of traffic exiting from I-95 South onto I-295 South, which is the assumed direction of most traffic diverted from or to I-95 southbound.

Negative impacts resulting from non-traffic DMS messages were investigated at DMS 6, a high-traffic location on I-95 near the central business district at mile marker 66.1.

Selection of Performance Measures

Based on the literature review, measures reflecting traffic diversions and other impacts of information provided via the DMS were identified and assessed for their ability to reflect changes in driver behavior. The performance measure selected for diversion analysis was percentage of diverted traffic. The performance measure selected for the impacts of non-traffic messages was speed.

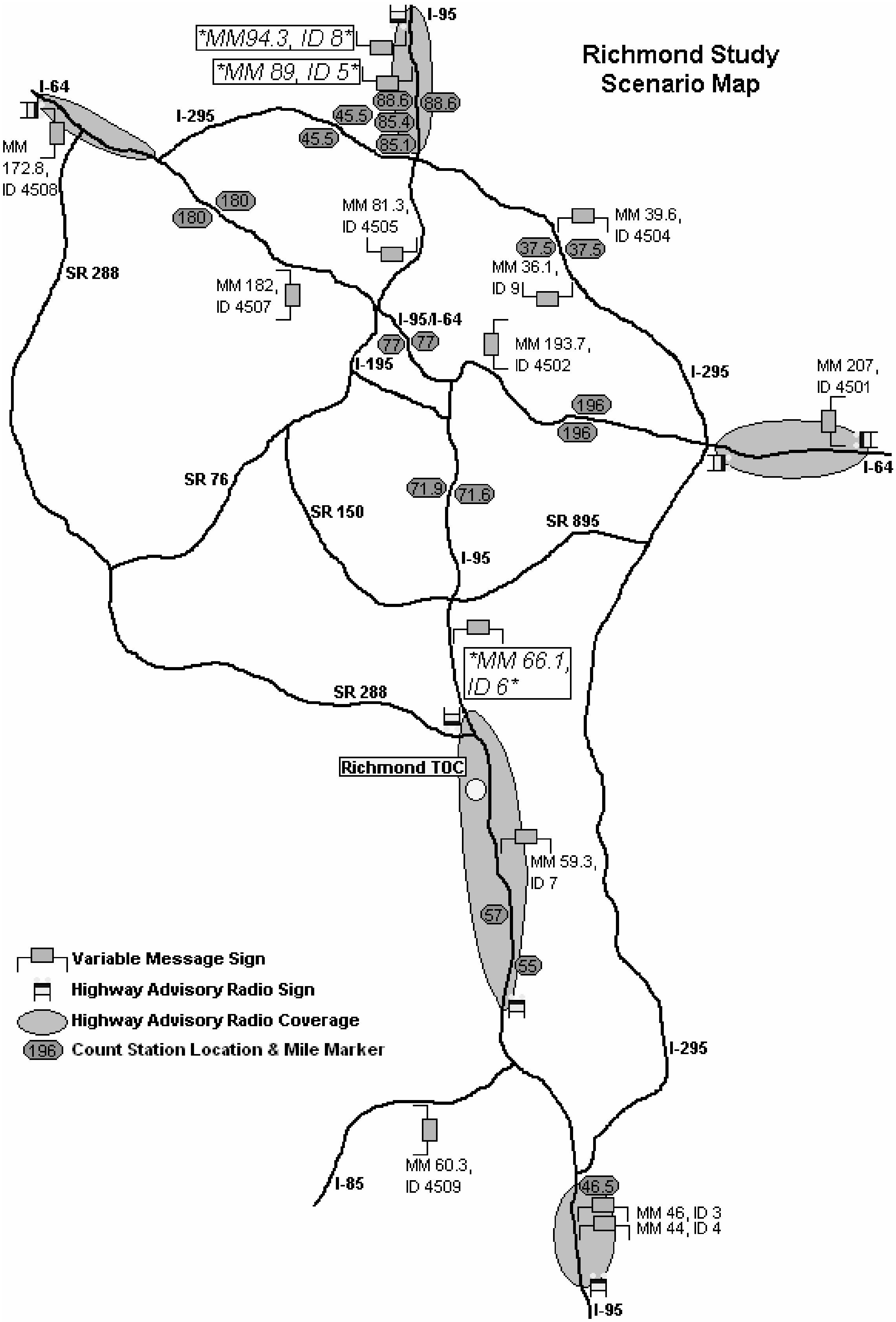

Figure 1. Richmond Study Scenario Map (1 in = approximately 5 mi)

Development and Implementation of Data Collection Plan

Diversion Analysis

Archived data on traffic flows for incident cases and normal situations on I-95 were collected for the diversion study area from the Smart Travel Laboratory (STL) at the University of Virginia. These data are reported to the STL from the Richmond TOC daily for 5-min intervals to comprise several databases: posted messages are archived in a DMS message database; volume, occupancy, and speed information from area count stations make up a traffic flow database; and incidents are logged in a separate database.

The incident and DMS message databases were first queried for incident scenarios and then coupled with data from the traffic flow database. Then, archived data for 4 times as many non-incident and non-holiday scenarios from the same time of day and day of week as the given incident scenario were used to determine the basis for calculating the percentage/volume of I-95 traffic that had been diverted. The time period queried for each count station was adjusted to account for the travel time of traffic first viewing the message to reach the count station. Traffic volume data from the corresponding count stations were then queried beginning with the adjusted time based upon when the message was first displayed to the end of the adjusted travel time for the farthest count station. All relevant scenarios from March 2005 through April 2008 were included and then organized based on information given on DMS messages.

Non-Traffic Speed Analysis

For non-traffic message speed analysis, three Wavetronix sensors were set up near DMS 6 during a scheduled period for non-traffic messages (see Figure 2). The first sensor was placed about 0.5 mi upstream of the DMS, before it is visible to drivers. The second sensor was placed about 0.1 mi before the DMS, where it could be read; it was expected that drivers would slow down. The third sensor was set up about 395 ft (0.07 mi) after the DMS, by which point it was assumed drivers would have resumed a normal speed, to detect any downstream congestion that might affect speeds at the previous two sensors. Data were collected at these three locations from Monday, August 25, 2008, at 9:44 A.M. to Thursday, August 28, 2008, at 8:50 A.M., during which time three non-traffic messages and two roadwork messages were posted on the DMS (see Table 1). Data at each site were collected in 20-sec intervals per lane for volume, occupancy, speed, 85th percentile speed, class of vehicle, headway, gap, and speed binned by 5-mph increments.

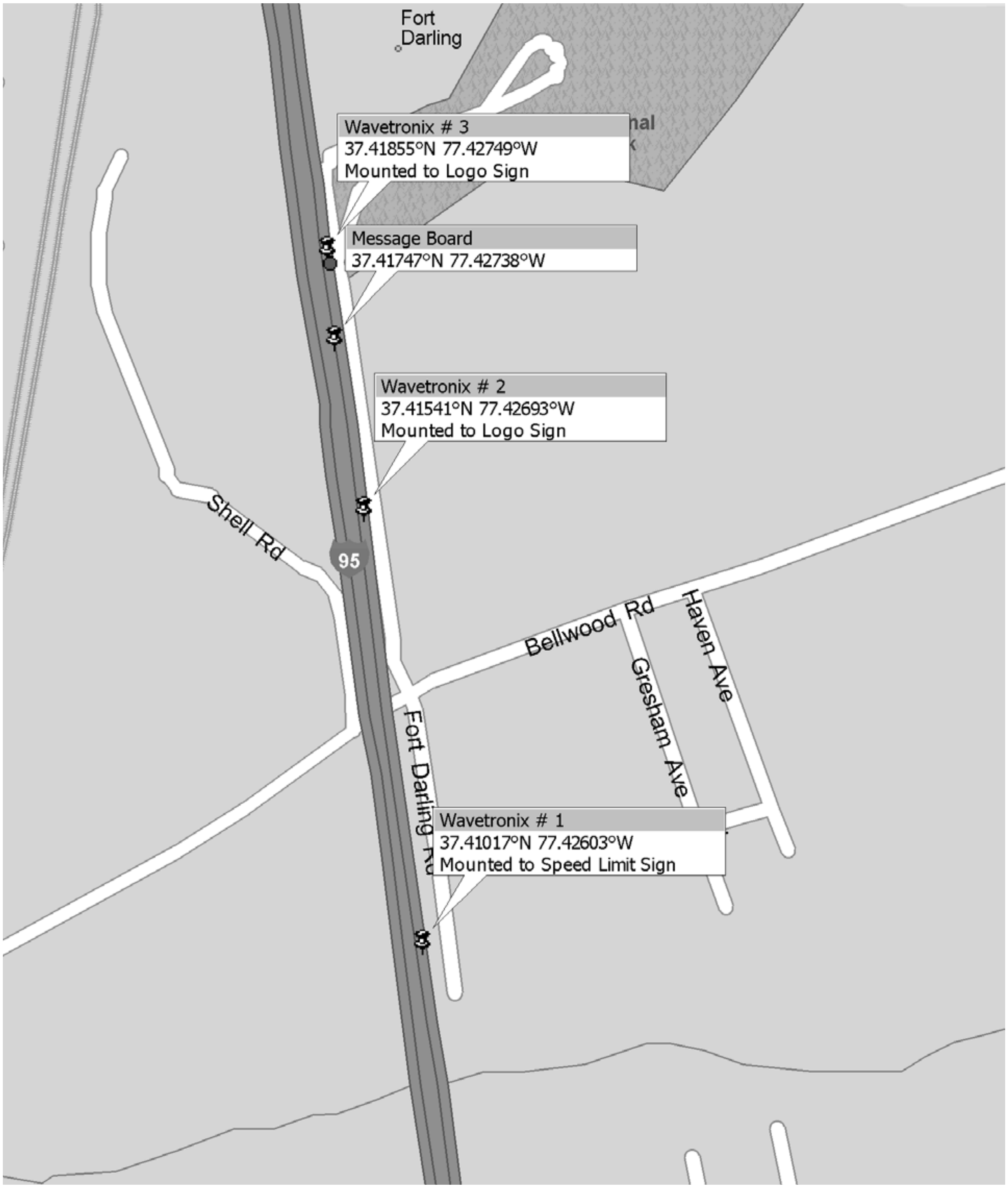

Figure 2. Location of Wavetronix Sensors in Relation to DMS

Table 1. Messages Posted on DMS During Data Collection

Message On	Message Off	Message
8/25 18:00	8/25 20:00	BUCKLE UP FOR SAFETY
8/26 12:02	8/26 14:02	BUCKLE UP FOR SAFETY
8/26 21:12	8/26 21:49	ROAD WORK 8 MILES ONE LANE CLOSED USE CAUTION
8/26 21:57	8/27 1:53	ROAD WORK 7 MILES ONE LANE CLOSED USE CAUTION
8/27 19:08	8/27 21:08	BUCKLE UP FOR SAFETY

Data Analysis

Diversion Scenarios

DMS messages were separated into two diversion scenarios: (1) an incident on the primary freeway, I-95, encourages diversion of I-95 traffic to an alternate route, I-295; and (2) an incident on an intersecting freeway, I-295, encourages exiting I-295 traffic to remain on I-95 as an alternate route. Collected traffic data and DMS messages used for traffic diversion were matched for specific cases and evaluated using the performance measures identified in step 3. Messages were consolidated by incident to eliminate duplicated messages posted on DMS 5 and DMS 8. All diversion messages fit into one of the following six categories:

1. *Delays on I-95:* no guidance provided, warning of potential slowdown or incident ahead, e.g., "ACCIDENT AT EXIT 73, EXPECT DELAYS"

2. *Recommend alternate route for I-95 traffic:* warning of potential slowdown or incident ahead, alternate routes recommended, no specific route provided, e.g., "ACCIDENT AT EXIT 75, EXPECT DELAYS, USE ALT ROUTE"

3. *Recommend I-295 diversion for I-95 traffic:* warning of potential slowdown or incident ahead, I-295 South recommended as alternate route for through traffic, e.g., "ACCIDENT EXIT 75, THRU TRAFFIC USE I-295 SOUTH"

4. *Delays on I-295 South:* no guidance provided, warning of potential slowdown or incident on I-295 South, e.g., "ACCIDENT, I-295 SOUTH AT EXIT 43, EXPECT DELAYS"

5. *Recommend alternate route for I-295 southbound traffic:* warning of potential slowdown or incident on I-295 South, alternate routes recommended, no specific route provided, e.g., "ACCIDENT, I-295 SOUTH, USE ALTERNATE ROUTES"

6. *Recommend I-95 diversion for I-295 South traffic:* warning of potential slowdown or incident ahead, I-95 recommended as alternate route for I-295 South traffic, e.g., "ACCIDENT, I-295 SOUTH AT EXIT 34, THRU TRAFFIC USE I-95 AS ALTERNATE."

After the data were organized, the number of incidents and quantity of data analyzed by the aforementioned message types were as indicated in Table 2.

Table 2. Quantity of Data Analyzed by Message Type

Message Type	Hours of Data	No. of Incidents	No. of Data Points
1	35.25	32	400
2	9.55	10	90
3	42.33	34	610
4	19.58	9	235
5	1.77	3	22
6	1.00	2	12

Data were classified and sorted to establish a base case, and then values for various cases were assigned in order to perform the statistical analysis. Values were assigned to data based on the following:

1. whether or not there was an incident

2. type of message being displayed (i.e., as based on the six categories previously provided) or whether no message was displayed

3. month the data were collected

4. seasonal variation for March through May, June through August, September through November, and December through February

5. time-of-day variations from 6 A.M. to 10 A.M., 10 A.M. to 4 P.M., 4 P.M. to 8 P.M., and 8 P.M. to 6 A.M.

6. number of lanes listed as closed

7. incident type displayed on the DMS as “ACCIDENT,” “ROADWORK,” “TRAFFIC,” “DISABLED VEHICLE,” “ROAD CLOSED,” or “VEHICLE FIRE” or no incident displayed

8. whether the message listed a “MAJOR ACCIDENT,” “ACCIDENT,” or neither

9. whether the message displayed “ALTERNATE,” “ALT,” or neither

10. number of phases of the message displayed at the time or if no message was displayed

11. whether the message was displayed on DMS 8, DMS 5, both, or neither

12. mile marker displayed for the incident location on either I-295 or I-95 or zero if none listed; mile markers were then binned according to proximity, with a goal of about 50 points per set. For I-95, bins are for mile markers 84, 81-83, 80, 79, 78, 76, 75, 74, 73, 69, 62-67, and 54-58. For I-295, one bin is for incidents before the

I-64 interchange, mile markers 33-43, and one is to include incidents at and after the I-64 interchange, mile markers 22-28

13. whether messages designate the number of lanes closed, number of lanes open, no message, or not listed in the message

14. whether the message read only "LEFT" or "RIGHT" lane(s) closed, only indicated the number of lanes affected, both, neither, or no message displayed.

Non-Traffic Messages

All data between 21:08 and 12:00 were discarded to make the best comparison for analysis, since all non-traffic messages were posted between the hours of 12:00 and 21:08. Times with roadwork messages posted were discarded since these were posted during late hours with low traffic volumes. A separate dataset was created where all data between 14:02 and 18:00 were also eliminated to remove the effects of peak hour traffic from analysis; no non-traffic messages were posted during this time. Thus, the analysis time was only when a non-traffic message had been posted on one of the three days of data collection.

RESULTS AND DISCUSSION

Literature Review

A number of ideas for improving the quality of DMS service gleaned from the literature review are applicable to the study at hand. First, it is important to be consistent in displaying messages. Consistent message formats reduce the time required by drivers to comprehend the message.[6] Second, to distinguish better the urgency of messages, low-frequency messages should be displayed in "title case" (i.e., only the first letter of a word is capitalized) instead of in "ALL CAPS" (i.e., all letters in a word are capitalized). The idea behind this guidance is that title case would be used for safety messages to denote less emphasis than for incident messages.[9] Third, providing estimates of travel times for route and alternate or length of delay, if they can be reasonably accurate, can encourage diversion.[4] Drivers typically know the additional amount of time an alternate route requires; thus, providing delay information can justify diversion.

The literature also encourages using one-phase messages where possible. A single message phase may be more effective, giving drivers more time to read and process the complete message[10,11] because less information would be provided with no second phase; one-phase messages may be best employed for diverting traffic from I-295 South to I-95. Discussions with the Richmond TOC identified an application for this guidance where complementary one-phase messages would be placed on DMS 5 and 8, one alerting drivers of the incident, the second encouraging an alternate route; for example, DMS 8 would display "ACCIDENT, 7 MILES, 1 LANE OPEN" and DMS 5 would show "ACCIDENT, PAST EXIT 84, USE I-295 SOUTH," with each being a single phase. Especially with two consecutive DMS available in the

Richmond study area, using a complementary one-phase message on each DMS might be an effective application.

An innovative approach to display DMS messages is to employ "staircase" or left-justified messages. With a staircase message, left, center, and right justification is used for the top, center, and bottom lines, respectively. An untested idea in the United States, an Australia study showed that driver comprehension improved 10 percent with a left-justified or staircase configuration of messages as opposed to center-justified messages.[7]

Another approach considers using DMS on major arterials to encourage diversion before drivers enter a freeway.[4] In this manner, traffic might be more likely to remain on the arterial network and prevent increased congestion on both the incident segment and alternate highway route.[4] The *Dynamic Message Sign Message Design and Display Manual*[6] published by the Texas Transportation Institute provides an acceptable standard for effective message design for various scenarios.

Although much research has been performed to provide guidance and recommendations for message design, diversion, and posting of non-traffic messages, little, if any, work has been done to investigate the effects of DMS on diversion when a comparable-distance interstate highway is available as an alternate route.

The literature also discussed ideas for the analysis of the use of various wordings, such as "ALT" versus "ALTERNATE."[6] Although studies have been conducted regarding the wording of messages, driver responsiveness can vary by region.[6]

Data Analysis

Diversion Scenarios

Data Analysis for Diversion to I-295

Data were entered into SPSS for descriptive statistics to investigate trends in diversion rates. The following tables show the mean and standard deviation for the percent of traffic exiting to I-295 from I-95 South at a 95 percent confidence interval. Further, the *t*-test was performed between each variable and the non-incident case to validate the significance of the diversion rates compared to a base case; likewise, *p*-values were used in other tables to denote the significance of seasonal and time-of-day comparisons. As shown in Table 3, the average percentage of traffic exiting to I-295 South was 29.9 percent, which was used as the base rate to calculate diversion rates to show trends. The diversion rate from I-95 can be calculated using Equation 1.

$$Diversion\ \ Rate_{To\ I-295} = \frac{Mean_{exiting\ \ traffic\ \ for\ \ message\ \ type} - Mean_{exiting\ \ traffic\ \ with\ \ no\ \ message}}{1 - Mean_{exiting\ \ traffic\ \ with\ \ no\ \ message}} \quad \text{[Eq. 1]}$$

For this study scenario, the diversion rate describes the percentage of southbound traffic that changes course to I-295 southbound (B, see Figure 3) after being informed of an incident downstream on I-95 southbound (A, see Figure 3) by DMS on I-95 southbound before the interchange (C, see Figure 3).

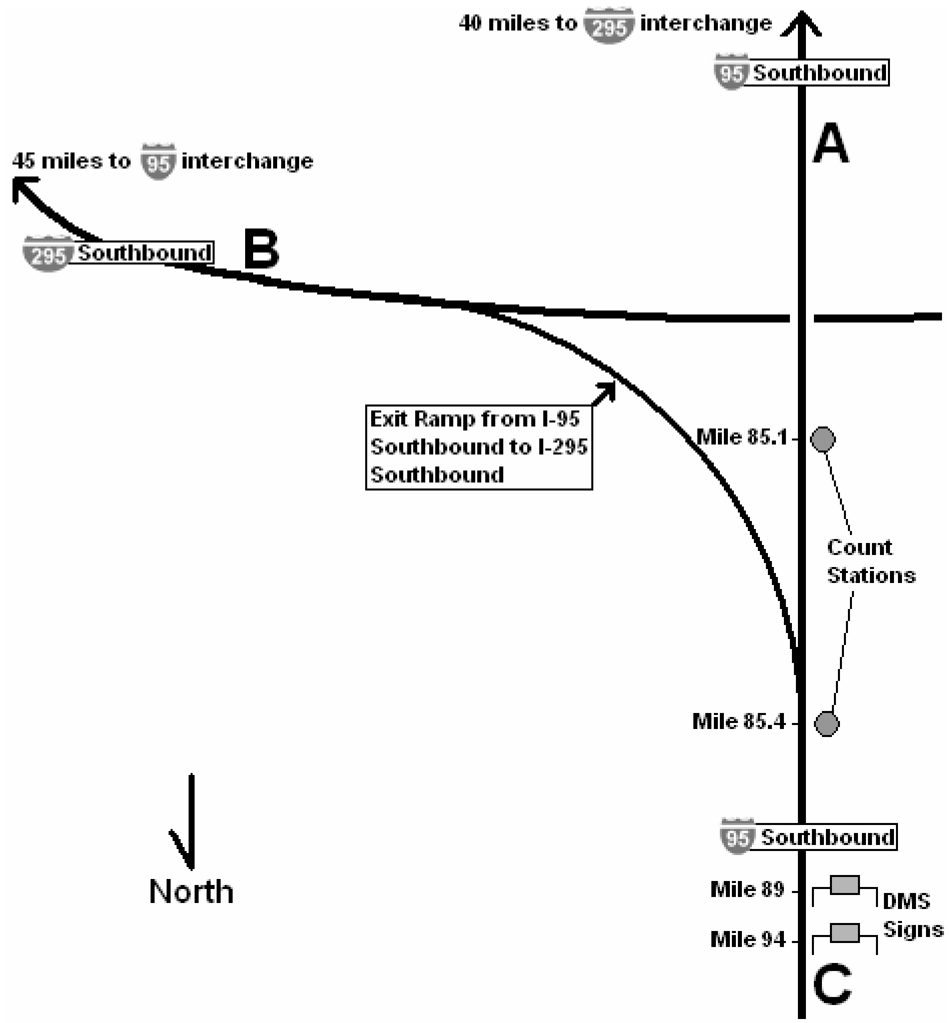

Figure 3. Study Scenario for Diversion to I-95 South (C) to I-295 South (B) When Incident Is on I-95 South (A).

Equation 1 is first used to set a base case for diversion rates by message type. Additional comparisons are then made to determine diversion rates by season and time of day, the number of lanes closed, the number of message phases, incident location, and various wording differences such as “LANES OPEN” vs. “LANES CLOSED” or “ALT” versus “ALTERNATE.”

As message intensity increases to suggest problems ahead (message type 1), recommend an alternate route (message type 2), and finally recommend I-295 as an alternate route (message type 3), the percentage of traffic exiting increases to 37.9, indicating increasing diversion rates up to 11.3 percent.

Table 3. Percentage Exiting to I-295 for Each Message Type

Message Type	Mean % Exiting to I-295	95% Standard Deviation	Data Points Analyzed	*t*-test Significance	% Diversion
0: No Incident	29.9	0.082	4089	-	-
1: No Guidance Provided	33.4	0.078	400	8.53	5.0
2: Alternate Route Recommended	36.4	0.075	90	8.12	9.3
3: I-295 Recommended as Alternate Route	37.9	0.104	610	18.17	11.3

Further, the general linear model (GLM), which can be analyzed using SPSS, is a flexible statistical model that integrates normally distributed dependent variables and categorical or continuous independent variables.[12] Outputs include tests of between-subject effects and estimated marginal means. This model was used in the data analysis.

Diversion to I-295 by Season and Time of Day. Comparing diversion by month, higher diversion rates occurred in February, May, June, and September (see Table 4). However, these apparent increases in diversion may be attributable only to increased trips onto I-295 South during these months.

Table 4. Percentage Exiting to I-295 vs. Month

Message Posted	Month	Mean % Exiting to I-295	95% Standard Deviation	No. Data Points Analyzed	*t*-test Significance	% Diversion
No	January	27.4	0.056	43[a]	-	-
	February	28.5	0.106	240	-	-
	March	29.6	0.081	549	-	-
	April	30.0	0.078	768	-	-
	May	31.4	0.064	706	-	-
	June	31.4	0.072	89	-	-
	July	27.6	0.062	41[a]	-	-
	August	27.7	0.097	332	-	-
	September	28.1	0.100	309	-	-
	October	31.0	0.079	330	-	-
	November	31.1	0.078	429	-	-
	December	29.9	0.083	253	-	-
Yes	January	29.9	0.082	7[a]	0.78[a]	3.4
	February	32.3	0.042	83	6.71	12.1
	March	38.4	0.119	89	4.91	5.9
	April	34.1	0.080	200	5.78	5.5
	May	33.8	0.084	132	8.51	10.9
	June	37.6	0.079	89	5.74	**12.8**
	July	38.9	0.100	20[a]	4.64	**15.6**
	August	35.6	0.064	109	9.73	8.1
	September	38.1	0.132	108	7.19	11.7
	October	35.2	0.105	116	3.93	7.5
	November	35.9	0.083	66	4.41	8.5
	December	35.2	0.088	81	4.78	7.5

Values in bold indicate noteworthy low or high values of diversion.
[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points.

Data were also analyzed in SPSS using a GLM. The dependent variable was the percentage of traffic exiting to I-295 South. First, the significance of the findings between season, time of day, and message type was verified as shown in Table 5.

The estimated marginal mean percentage of traffic exiting to I-295 South and the 95 percent confidence interval alongside the mean diversion rates for season and message are shown in Table 6. By season, the summer months (June–August) showed the highest rates of diversion, despite a decreased percentage exiting to I-295 with no message posted, perhaps as a result of increased recreational traffic versus commuters (see Table 6). The baseline for calculating diversion rates was chosen to be the control, message type 0, for each period analyzed.

Table 5. General Linear Model Tests of Between-Subjects Effects for Season, Time of Day, and Message Type

Source	Type III Sum of Squares	df	Mean Square	*F*	Sig.[a]
Corrected Model	9.481[b]	52	.182	29.571	0.000
Intercept	61.270	1	61.270	9937.680	0.000
Season	.153	3	.051	8.258	0.000
Time of Day	.465	3	.155	25.119	0.000
Message	3.091	3	1.030	167.126	0.000
Season * Time Period	.295	9	.033	5.314	0.000
Season * Message	.510	9	.057	9.195	0.000
Time Period * Message	.945	9	.105	17.037	0.000
Season * Time Period * Message	.493	16	.031	5.003	0.000
Error	31.666	5136	.006		
Total	547.874	5189			
Corrected Total	41.146	5188			

[a]*p*-values denoted as "sig" are less than 0.05 at 0.000.
[b]R squared = 0.230 (adjusted R squared = 0.223).

Table 6. Estimated Marginal Means Between Season and Message Type

Season	Message Type	Mean % Exiting to I-295	Standard Error	95% Confidence Interval		Mean Diversion Rate (%)
				Lower Bound	Upper Bound	
March-May	0	29.7	0.002	29.3%	30.0%	-
	1	31.5	0.008	29.8%	33.1%	**2.6**
	2	33.0[a]	0.015	30.0%	35.9%	**4.7**
	3	36.8	0.006	35.6%	38.0%	10.1
June-August	0	28.5	0.004	27.7%	29.4%	-
	1	34.5	0.007	33.1%	35.9%	8.4
	2	40.0[a]	0.032	33.7%	46.3%	**16.1**
	3	43.5[a]	0.011	41.4%	45.6%	**21.0**
September-November	0	28.8	0.003	28.1%	29.5%	-
	1	33.1%[a]	0.015	30.1%	36.1%	6.0
	2	38.6%[a]	0.013	35.9%	41.2%	13.8
	3	39.1%	0.006	38.0%	40.2%	14.5
December-February	0	29.0%	0.004	28.2%	29.8%	-
	1	35.6%[a]	0.009	33.7%	37.4%	9.3
	2	32.3%[a]	0.03	26.5%	38.2%	4.6
	3	36.4%	0.012	34.0%	38.7%	10.4

Values in bold indicate noteworthy low or high values of diversion.
[a]Based on modified population marginal mean.

The estimated marginal mean percentage of traffic exiting to I-295 South and the 95 percent confidence interval with the mean diversion rates for time period and message are shown in Table 7. This table shows that diversion rates were higher during non-peak hours, particularly overnight from 8 P.M. to 6 A.M.

Table 7. Estimated Marginal Means Between Time Period and Message

Time Period	Message Type	Mean % Exiting to I-295	Standard Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Mean Diversion Rate (%)
6 A.M.-10 A.M.	0	25.7	0.003	25.1%	26.4%	-
	1	29.7	0.009	28.0%	31.4%	5.4
	2	36.2[a]	0.015	33.3%	39.1%	14.1
	3	32.3	0.009	30.5%	34.0%	8.9
10 A.M.-4 P.M.	0	32.6	0.004	31.8%	33.4%	-
	1	39.4[a]	0.013	36.8%	42.0%	10.1
	2	35.4[a]	0.017	32.1%	38.7%	4.2
	3	41.8	0.01	39.9%	43.8%	13.6
4 P.M.-8 P.M.	0	31.1	0.002	30.6%	31.5%	-
	1	32.0	0.007	30.6%	33.4%	1.3
	2	35.1	0.016	31.8%	38.3%	5.8
	3	38.0	0.007	36.6%	39.4%	10.0
8 P.M.-6 A.M.	0	26.6	0.004	25.8%	27.4%	-
	1	34.9[a]	0.012	32.6%	37.1%	11.3
	2	41.2[a]	0.045	32.3%	50.1%	**19.9**
	3	43.8[a]	0.009	42.1%	45.5%	**23.4**

Values in bold indicate noteworthy low or high values of diversion.
[a]Based on modified population marginal mean.

Diversion to I-295 vs. Lanes Closed. As might be expected, a trend toward increased diversion occurred, regardless of message type, when more lanes were closed on the highway ahead (see Table 8). Using the GLM, the significance of results between season, time of day, and number of lanes closed was verified, with all *p*-values being less than 0.05 at 0.000.

Messages vary in how they state that lanes are closed, and this, too, was examined (see Table 9). For the same incident, for example, a message could say “LEFT LANES CLOSED” (lane direction–only case), “TWO LEFT LANES CLOSED” (lane direction and number case),

Table 8. Percentage Exiting to I-295 vs. Number of Lanes Closed and Message Type

Message Type	No. of Lanes Closed	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	t-test Significance	% Diversion
0: No Incident	0	29.9	0.082	4089	-	-
1: No Guidance Provided	0	33.1	0.073	201	6.03	4.5
	1	33.0	0.08	139	4.49	4.4
	3	35.2	0.088	60	4.64	7.5
2: Alternate Route Recommended	0	35.0	0.069	54	5.38	7.2
	2	39.7	0.078	30[a]	6.85	13.9
	3	33.3	0.074	6[a]	1.12	4.8
3: I-295 Recommended as Alternate Route	0	36.1	0.091	262	10.75	8.8
	2	34.7	0.097	126	5.49	6.8
	3	41.8	0.11	222	15.88	16.9

[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points.

Table 9. Percentage Exiting to I-295 vs. Direction/Number of Lanes Closed

Lanes Affected	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
No Incident	29.9	0.082	4089	-	-
"LEFT" or "RIGHT" Lanes	32.4	0.093	165	3.40	3.5
No. of Lanes Affected	36.8	0.085	131	9.16	9.8
Both	30.7	0.058	7*	0.34[a]	1.1
Neither	36.8	0.096	797	18.99	9.8

[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points.

"TWO LANES CLOSED" (numbers only case), or "INCIDENT AHEAD" (no direction/number information). A lane direction–only case was associated with a much lower diversion rate of 3.5 percent versus listing either numbers only or no direction/number information, both of which had a diversion rate of 9.8 percent. Too few data points existed to compare adequately the lane direction and number case. Using the GLM, the significance of these values between season, time of day, and direction/number of lanes closed was verified, with all *p*-values being less than 0.05 at 0.000.

When lanes are closed on the highway ahead, two message types can be used to convey this to drivers: some messages display how many lanes remain open, and others show how many are closed. Although listing the number of lanes open seems more effective for a type 2 message, listing the number of lanes closed was more effective for a type 3 message (see Table 10). Moreover, although diversion was increased when the message indicated the number of lanes that were open versus number of lanes closed, diversion was actually higher with no mention of lane restrictions (see Table 11).

Table 10. Percentage Exiting to I-295 vs. Listing of "Open" or "Closed" and Message Type

Message Type	Lanes "OPEN" or "CLOSED"	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
0: No Incident	No Message	29.9	0.082	4089	-	-
1: No Guidance Provided	No. of Lanes Closed	33.8	0.079	190	6.64	5.5
	Not Listed in Message	33.0	0.077	210	5.67	4.4
2: Alternate Route Recommended	No. of Lanes Closed	33.3	0.074	6[a]	1.12	4.9
	No. of Lanes Open	39.7	0.078	30[a]	6.91	**14.0**
	Not Listed in Message	35.0	0.069	54	5.38	7.2
3: I-295 Recommended as Alternate Route	No. of Lanes Closed	40.7	0.112	267	15.49	**15.4**
	No. of Lanes Open	34.4	0.094	80	4.25	6.4
	Not Listed in Message	36.1	0.091	263	10.77	8.8

[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points.

Table 11. Listing of “Open” or “Closed” vs. Number of Lanes Closed

Lanes "OPEN" or "CLOSED"	No. of Lanes Closed	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
No Incident	0	29.9	0.082	4089	-	-
No. of Lanes Closed	1	33.0	0.080	139	4.49	4.4
	2	35.2	0.105	45 [a]	3.37	**7.4**
	3	40.6	0.107	279	16.38	15.2
No. of Lanes Open	2	35.8	0.093	110	6.59	**8.4**
Not Listed in Message	0	34.8	0.083	517	12.66	6.9
	2	35.9		1 [a]		**8.5**
	3	31.4	0.147	9 [a]	0.31 [a]	2.1

Values in bold indicate noteworthy low or high values of diversion.
[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points.

Table 10 compares diversion rates for displaying the number of “lanes closed” versus the number of “lanes open” by diversion message and shows “lanes open” messages to be more effective for messages suggesting alternate routes and “lanes closed” messages to be more effective for diverting traffic specifically to I-295. Table 11 shows a more level comparison by showing the message language by the number of lanes closed, and it is seen that messages displaying the number of lanes open in the database apply only to incidents with two lanes blocked; the percentage exiting to I-295 South with a “LANES OPEN” message was roughly the same as the overall average of 35.8 percent during an incident with two lanes blocked. The GLM was employed to check for significance between season, time of day, and listing of lanes “OPEN” or “CLOSED”; all *p*-values were less than 0.05, and thus significant at 0.000, except for season, which was not a significant variable for this case.

Diversion to I-295 with One-Phase Messages. There is limited deployment of one-phase messages for incidents since less information can be presented, allowing only type 1 messages to be analyzed for number of phases; the number of phases for a message is simply the number of panels required to include all of the words of a message; thus a two-phase message shows only one-half of the full message at a time, flashing between the two parts every few seconds. In this comparison, the two-phase messages have a 1.1 percent higher diversion rate (see Table 12). Insufficient data limit the conclusions that can be made regarding the deployment of one-phase messages. The GLM was employed to check for significance between season of year, time of day, and number of phases; all *p*-values were less than 0.05, and thus significant at 0.000, except for season, which was not a significant variable for this case.

Table 12. Percentage Exiting to I-295 vs. Number of Phases and Message Type

Message Type	No. of Phases	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
0: No Incident	0	29.9	0.082	4089	-	-
1: No Guidance Provided	1	32.8	0.069	103	4.19	4.1
	2	33.6	0.081	297	7.59	5.2

Diversion to I-295 by Incident Location

When diversion rates were examined by incident location provided in the message, diversion rates were highest, 12.8 percent, where the incident was at mile marker 76, immediately before the I-64 East interchange in downtown Richmond (see Table 13). Higher diversion rates also occurred when the incident was beyond the I-64 East interchange, particularly between mile markers 62 and 67, with 11.8 percent diversion. These high diversion rates may be due to the ease provided a driver to bypass the incident by taking I-295 and returning to I-95 via I-64 West and SR 10, immediately beyond the respective incident locations. Although having only 47 data points, the I-64 East interchange at mile marker 75 (see Table 16) stands out as having the lowest diversion rate at 3.6 percent; diversion rates for incidents at immediately previous or subsequent interchanges were12.8 and 9.7 percent, respectively. The standard deviation for this location was particularly low despite only 47 data points, with a value of 0.0507 for a 95 percent confidence interval. The GLM was employed to check for significance between season, time of day, and incident location; all *p*-values were less than 0.05, and thus significant, except for season, which was not a significant variable for this case.

Table 13. Percentage Exiting to I-295 vs. Mile Marker Bin of Incident

Mile Marker (Bin)	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
No Msg	29.9	0.082	4089	-	-
84	34.8	0.11	71	3.74	6.9
81-83	33.0	0.09	61	2.67	4.4
80	33.5	0.077	92	4.43	5.1
79	34.5	0.092	61	3.88	6.5
78	35.2	0.095	122	6.09	7.5
76	38.9	0.101	224	13.10	**12.8**
75	32.4	0.051	47[a]	3.34	**3.6**
74	36.7	0.102	124	7.35	**9.7**
73	36.8	0.115	79	5.31	9.8
69	36.6	0.066	73	8.56	9.5
62-67	38.2	0.058	74	12.09	11.8
54-58	35.9	0.109	72	4.65	8.5

Values in bold indicate noteworthy low or high values of diversion.
[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points

Diversion to I-295 and Word Choice. The wording of messages varies based on the personal preference of DMS operators at the Richmond TOC. A library of messages is available for use, with multiple messages being applicable to any incident, dependent upon the amount of information known about the incident. However, the analysis of the wording and information provided here shows that some words or units of information were more effective than others for influencing the diversion of traffic.

Using the abbreviation "ALT" in a message appeared to cause a decreased rate of diversion at 8.5 percent versus using the full word "ALTERNATE," which diverted about 11.1 percent of traffic (see Table 14). Without the mention of an "ALT" or "ALTERNATE" route, however, diversion rates were only 7.8 percent. The GLM was employed to check for significance between season, time of day, and "ALT" vs. "ALTERNATE"; all *p*-values were less than 0.05, and thus significant, except for season, which was not a significant variable for this case.

Table 14. Percentage Exiting to I-295 vs. Usage of "ALT" or "ALTERNATE" and Message Type

Message Type	ALT / ALTERNATE	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
0: No Incident	Neither	29.9	0.082	4089	-	-
1: No Guidance Provided	Neither	33.4	0.078	400	8.53	4.9
2: Alternate Route Recommended	Alternate	36.0	0.065	26[a]	4.74	8.7
	Alt	36.6	0.079	64	6.73	9.5
3: I-295 Recommended as Alternate Route	Neither	38.5	0.099	303	14.75	12.2
	Alternate	37.9	0.115	235	10.51	11.4
	Alt	35.2	0.085	72	5.25	7.5
All Incident Messages	Alternate	37.7	0.111	261	11.16	**11.1**
	Alt	35.9	0.082	136	8.39	**8.5**

Values in bold indicate noteworthy low or high values of diversion.
[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points

As might be expected, for all message types, using "MAJOR ACCIDENT" rather than "ACCIDENT" produced a 3.7 percent higher rate of diversion (10.4% versus 6.6%) (see Table 15). The GLM verified the significance between season, time of day, and use of "MAJOR" accident, with all *p*-values being less than 0.05.

Table 15. Percentage Exiting to I-295 vs. "ACCIDENT" and "MAJOR ACCIDENT" and Message Type

Message Type	"MAJOR ACCIDENT" or "ACCIDENT"	Mean % Exiting to I-295	95 Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
0: No Incident	Neither	29.9	0.082	4089	-	-
1: No Guidance Provided	Neither	33.1	0.082	73	3.30	4.5
	Major Accident	34.8	0.077	58	4.81	6.9
	Accident	33.2	0.077	269	6.78	4.7
2: Alternate Route Recommended	Neither	31.3	0.075	4[a]	0.37[a]	2.0
	Major Accident	38.3	0.078	37[a]	6.59	12.0
	Accident	35.4	0.071	49[a]	5.43	7.9
3: I-295 Recommended as Alternate Route	Neither	39.2	0.101	223	13.51	13.2
	Major Accident	37.7	0.116	215	9.73	11.1
	Accident	36.5	0.090	172	9.45	9.4
All Incident Messages	Major Accident	37.2	0.106	310	11.86	**10.4**
	Accident	34.6	0.083	490	11.86	**6.7**

Values in bold indicate noteworthy low or high values of diversion.
[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points

Diversion to I-295 by Incident Type. Sometimes the type of incident is listed in the message. Two particular types of incident messages seemed to have a greater influence on diversion (see Table 16). As should be expected, road closures produced the highest rate of diversion at 18.7 percent, but accidents also diverted 8.0 percent of traffic; without listing the type of incident, only 3.6 percent of traffic diverted, which is comparable to diversion if the incident is a "disabled vehicle." Using the GLM, significance between season, time of day, and number of lanes closed was verified, with all *p*-values being less than 0.05 at 0.000.

Table 16. Percentage Exiting to I-295 vs. Type of Delay Listed

Message Posted?	Type of Delay Listed	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
No	None	29.9	0.082	4089	-	-
Yes	None Listed	32.5	0.085	46[a]	2.04	**3.7**
	Accident	35.6	0.093	800	16.15	8.1
	Roadwork	32.4	0.054	4 [a]	0.92[a]	**3.6**
	Traffic	32.8	0.095	48[a]	2.11	4.1
	Disabled Vehicle	33.0	0.085	58	2.76	4.4
	Road Closed	43.0	0.087	136	17.31	**18.7**
	Vehicle Fire	39.9	0.039	8[a]	7.30	**14.3**
	Overall	36.1	0.096	1100	19.58	8.8

Values in bold indicate noteworthy low or high values of diversion.
[a]Low value does not meet pre-defined standards for significance, e.g., >50 data points.

Diversion to I-295 by DMS Used. In comparing diversion rates with which DMS are used, more traffic diverted with only DMS 8 displaying a message, 11.1 percent diversion, than with DMS 5, 4.3 percent diversion (see Table 17). Moreover, placing an independent message on DMS 5 in conjunction with DMS 8 had minimal impacts on diversion to I-295 South, with only 10.1 percent of traffic diverting in this circumstance. These findings are likely the result of the outdated technology being used on DMS 5. Before September 30, 2007, DMS 5 used flip-sign technology to present messages; a portable DMS was set up for an intermediate period before a new LED sign was formally placed there on May 23, 2008. The cause for a message being posted on only one DMS is typically an indicator of the other DMS being out of service. Using the GLM, the significance between season, time of day, and DMS used was verified, with all *p*-values being less than 0.05.

Since all other data analysis was performed before the flip-sign technology on DMS 5 was taken out of service, a new dataset was organized to validate the conclusions. The new dataset was based on selected incidents from November 2008 through May 2009. A slight increase in diversion was noted when both DMS were displaying messages. Because of the limited display of incident messages on DMS 8, however, it was difficult to draw significant conclusions. Further, in this dataset, DMS 8 and 5 were used individually only for a "No Guidance Provided" message, where limited diversion is expected.

Table 17. Percentage Exiting to I-295 vs. DMS Used

DMS Used	Mean % Exiting to I-295	95% Standard Deviation	No. of Data Points Analyzed	*t*-test Significance	% Diversion
Neither	29.9	0.082	4089	-	-
8	37.7	0.113	230	10.32	11.1
5	33.0	0.083	280	6.05	4.4
Both	37.0	0.090	590	18.11	10.1

Data Analysis for Diversion of Exiting I-295 Traffic to I-95

For this study scenario, the diversion rate describes the percentage of southbound traffic exiting to I-295 (D, see Figure 4) that changes course to I-95 southbound (A, see Figure 4) after being informed of an incident downstream on I-295 southbound (B, see Figure 4) by DMS signs on I-95 southbound before the interchange (C, see Figure 4).

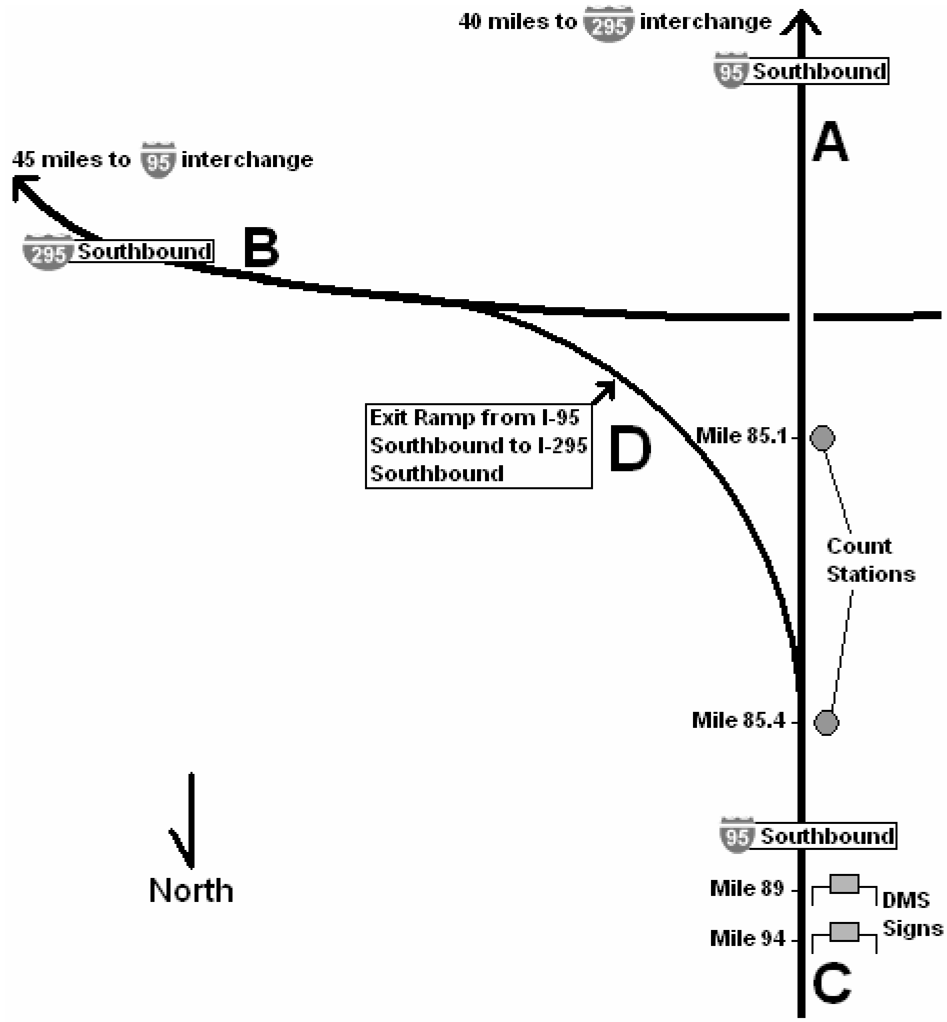

Figure 4. Study Scenario for Diversion of Traffic Exiting to I-295 South (D) From I-95 (C) to I-95 South (A) When Incident Is on I-295 South (B).

Data were treated as in the previous diversion scenario, with the dependent variable still being the percentage of traffic exiting to I-295 South from I-95 South; thus, diversion for this scenario is implied by a lower percentage of traffic exiting to I-295 South. Equation 2 is used to calculate diversion of exiting I-295 traffic to I-95.

$$Diversion\ Rate_{To\ I-95} = \frac{Mean_{exiting\ traffic\ for\ message\ type} - Mean_{exiting\ traffic\ with\ no\ message}}{Mean_{exiting\ traffic\ with\ no\ message}} \quad \text{[Eq. 2]}$$

Because of a limited dataset, statistical analysis proved to be more difficult for cases where traffic was diverted from exiting to I-295 South to continue on I-95 than in the previous analysis scenario. Although sound conclusions were difficult to draw with this dataset, diversion for this scenario type was still useful and encouraged for future incidents. Further investigation, using this methodology, is recommended when additional data are available.

Non-Traffic Messages

Because of potential calibration discrepancies among the three Wavetronix sensors, direct speed comparisons among the three stations were not made. Thus, comparisons were made only at each station to compare safety message posted versus no message. In these comparisons, there were no statistically significant variations in vehicle speed either per lane or as a weighted average for any of the three stations (see Table 18). During the times that messages were shown on the DMS, there were higher volumes of vehicles on the road; traffic flow on the highway averaged 2,440 vehicles per hour during the times messages were shown and only 2,070 vehicles per hour in the same time intervals when messages were not displayed. In conclusion, on average, despite higher volumes of traffic, speeds slightly increased when messages were shown on the DMS for all locations.

These findings do not validate the comments received by the Richmond TOC regarding non-traffic messages, such as the following:

> [Twice] on Saturday . . . traffic went from 65 mph to a dead stop. In both incidents, the cause was the overhead sign [displaying], ‘Click it, or Ticket!’ It is my belief that emergency signs should be used only for emergencies. Flashing anything other than an emergency distracts drivers because they think a problem is ahead. As it turns out, the problem is your sign . . . . [8]

However, neither do they invalidate potential queuing issues. Although an infrequent problem, certain traffic conditions or message wordings could cause traffic to slow down for non-traffic messages.[13,14] This study investigated only a one-phase message, whereas “ozone action day” messages, for example, posted to discourage driving when weather conditions and emissions are likely to form high levels of harmful ground-level ozone, are two-phase messages. The increased number of words presented by two-phase messages take longer to read and can cause slowdowns, particularly during certain conditions, e.g., times with high traffic volumes or high percentages of non-local traffic.[6]

Table 18. Average Speeds by Location and Lane vs. Display of Non-Traffic Messages

Lane	Safety Message	Wavetronix Sensor Site Location: 1 (upstream of DMS) Mean Speed	95% Confidence Interval		2 (near DMS) Mean Speed	95% Confidence Interval		3 (downstream of DMS) Mean Speed	95% Confidence Interval		Difference of Location Mean Speeds 1-2	2-3	1-3
1	No	62.4	62.1	62.7	65.1	64.7	65.4	64.7	64.4	65.0	-2.7	0.3	-2.3
	Yes	62.7	62.3	63.1	66.2	65.7	66.6	65.2	64.8	65.6	-3.5	1.0	-2.5
2	No	65.8	65.6	66.0	71.1	70.9	71.4	67.6	67.4	67.7	-5.3	3.6	-1.7
	Yes	66.6	66.4	66.8	71.9	71.6	72.2	68.1	67.8	68.3	-5.3	3.9	-1.5
3	No	70.6	70.3	70.8	72.0	71.8	72.2	70.3	70.1	70.5	-1.5	1.7	0.2
	Yes	71.6	71.4	71.9	72.9	72.6	73.2	70.5	70.3	70.7	-1.3	2.4	1.1
Weighted Average	No	65.9	65.7	66.1	69.5	69.3	69.7	67.4	67.2	67.5	-3.6	2.1	-1.5
	Yes	66.4	66.2	66.6	70.3	70.1	70.6	67.7	67.5	67.9	-3.9	2.6	-1.3

CONCLUSIONS

Diversion

- *The results of this research indicate those elements of a message that are effective for a given scenario to encourage diversion.* Although some elements are ineffective in promoting diversion, they may be valuable for simply informing drivers of the situation ahead (e.g., which side of the highway has a disabled vehicle to avoid).

- *Increased traffic diversion is more likely when drivers are alerted to certain situations, such as a highway closure at a point ahead or an accident. Diversion is also increased when the message indicates two or three lanes are closed on the highway ahead.*

- *The wording in messages can influence the diversion of traffic.* Listing an incident as "MAJOR" and listing "ALTERNATE" instead of "ALT" produce increased diversion. Moreover, encouraging a specific alternate route, i.e., I-295, was more effective, with 11.1 percent diversion, but simply suggesting traffic seek an alternate route encouraged 9.3 percent diversion.

- *Indicating whether the left or right lanes are blocked is not necessary if the primary objective is diversion, since diverted vehicles will not be affected by the side of the road the incident affects;* in other words, for an incident on I-295, few drivers on I-95 will find this information useful. If diversion is desired, listing that one lane is closed is not recommended for this scenario since fewer drivers respond when provided this information, likely thinking that one less lane will not greatly worsen conditions. In addition, reviewing messages before they are posted can help decrease driver confusion: several messages in the database at DMS 8 refer to "I-295 NORTH" for points that are actually on I-295 South.

Non-Traffic Messages

- *Data from this study reported no significant variations in speed when a non-traffic message was posted.* However, the findings of this study do not exclude the possibility that certain conditions, such as a high percentage of drivers unfamiliar with the area, could cause queuing because of a message,. Moreover, the non-traffic message posted during the analysis period was a short, one-phase, two-line message that could be easily read and seen to be a simple non-traffic message.

RECOMMENDATIONS

1. *Management of VDOT's TOCs should issue guidance on DMS messaging to enhance diversion during incident scenarios.* This guidance should include the following:

   Be consistent in displaying messages. Consistent message formats reduce the time required by drivers to comprehend the message. Table 19 summarizes the recommended wording for messages based on the results of this study when the desired intention is to induce diversion or simply provide information; this should serve as a guide for TOC operators when posting a DMS message. For example, messages indicating "MAJOR DELAYS" instead of "MAJOR ACCIDENT/EXPECT DELAYS" should be used. Select measures that best encourage diversion are using the phrases "MAJOR ACCIDENT" or "MAJOR DELAYS" and listing I-295 as the recommended alternate route, as well as displaying the cause during times when two or three lanes are closed because of an accident.

Table 19. Summary of Recommendations for Wording of DMS Messages

Message Unit of Information	Recommended Display	
	Diversion Desired	**Information Only**
ALT/ALTERNATE	"ALTERNATE"	"ALT or ALTERNATE"
Alternate Route	List specific route, e.g., I-295	List general, e.g., "USE ALT ROUTE"
Accident Type	"MAJOR ACCIDENT"	"ACCIDENT"
Delay Type	"MAJOR DELAYS"	"EXPECT DELAYS"
Message Format	Left-justified or staircase	Left-justified or staircase
Left/Right Side	No	Yes
Incident Type	Accident, Road Closed	Disabled Vehicle
Closures	>1 Lane	1 Lane

- *Provide estimates of travel times for route and alternate or length of delay, if they can be reasonably accurate, to encourage diversion.* It is beneficial to provide estimates of travel times for route and alternate or length of delay, if they can be reasonably accurate, to encourage diversion. Drivers typically know the additional amount of time an alternate route requires; thus, providing delay information can justify diversion. One method to obtain this information might involve TOC staff using traffic cameras upstream of the incident to estimate the consequent length of queue in order to provide this information on a DMS to drivers.

- *Use one-phase messages where possible.* A single message phase may be more effective, giving drivers more time to read and process the complete message. In cases where consecutive DMS can be used in a coordinated fashion, complementary one-phase messages should be considered. The first DMS might alert drivers of the incident, and the second encourage an alternate route; for example, "ACCIDENT, 7 MILES, 1 LANE OPEN" on the first DMS and "ACCIDENT, PAST EXIT 84, USE I-295 SOUTH" on the second DMS, where each message is a single phase.

- *Use title case for low-frequency messages, instead of ALL CAPS.* Using title case for safety messages would denote less emphasis and urgency than incident messages.

- *Employ staircase or left-justified messages.* An untested idea in the United States, an Australia study showed that driver comprehension improved 10 percent with a left-justified or staircase configuration of messages versus center-justified messages.

2. *The staff of VDOT's TOCs should consider the following for the display of non-traffic messages to minimize the potential for queuing:*

- *Display non-traffic messages only during non-peak periods.* Additional time is required to post a new message if a message is already posted on the DMS. Thus, it is recommended that the display of non-traffic messages be limited to non-peak periods when the response time of posting incident information and resulting congestion is less critical.

- *Make non-traffic messages one phase in length.* A two-phase message may cause drivers to slow down to read the full message, whereas a single message phase requires less time for the driver to read and process the complete message.

3. *VDOT's operations regions should consider using DMS on major arterials to encourage diversion before entering a freeway.* In this manner, traffic might be more likely to remain on the arterial network and prevent increased congestion on both the incident segment and alternate highway route.

4. *The Virginia Transportation Research Council should consider sponsoring the following further research:*

- research to determine who is diverting (i.e., local or through traffic); the effect of an incident on the overall network, such as alternate routes that are being used instead of I-95, if not I-295; and controlled field tests to verify the recommendations and new message strategies

- when additional data are available, research regarding the diversion of exiting I-295 traffic to I-95 based on the methodology developed in this study

- research to determine the conditions that may cause queuing by non-traffic messages so that their use can be restricted during the times those conditions apply.

BENEFITS AND IMPLEMENTATION PROSPECTS

If the findings and recommendations of this research are implemented, the enhanced effectiveness of diversion strategies will result in reductions in delay, fuel consumption, and emissions as well as the potential for secondary accidents created by major incidents and other traffic flow disruptions. The *2009 Urban Mobility Report* from the Texas Transportation Institute estimated the total delay for motorists in Richmond to be 10,212,000 person-hours in 2007, with 59 percent of that delay resulting from incidents; the cost of this incident-induced congestion is about $119 million.[15] A modest 1 percent reduction in this cost attributable to better diversion strategies that use DMS more effectively would result in an annual cost savings of more than $1 million dollars in Richmond alone.

Since the research team worked with the Richmond TOC in developing the scope and conducting the study, the results are directed at their normal operations procedures and can be easily used to modify current practice. They should also be shared with other VDOT TOCs, where they may also be validated as beneficial.

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