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Effectiveness of VMS Using Empirical Loop Detector Data

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1. Introduction

Variable message signs (VMS) (also called Changeable Message Signs (CMS) or Electronic Message Signs (EMS)), are devices installed along the roadside to display messages of special events. They give warning of congestion, incidents, roadwork zones or speed limits on a specific highway segment. A complete message on a panel generally includes a problem statement indicating incident, roadwork, stalled vehicle etc; a location statement indicating where the incident is located; an effect statement indicating lane closure, delay, etc and an action statement giving suggestion what to do (New York DOT). They may ask vehicles to take alternative routes, limit travel speed, warn of duration and location of the incidents or just inform of the traffic conditions.

In Minnesota, the first VMS were deployed in the 1960's. The current VMS system consists of over 68 VMS, mainly on freeway or trunk highways. The VMS messages stipulated by the Minnesota Department of Transportation provide the following information:

(1) crashes including vehicle spin-out or rollover;
(2) stall affecting normal flow in a lane or on shoulders; (
(3) non-recurring congestion, residual effect of cleared crash;
(4) entire road closure;
(5) downstream exit ramp closure;
(6) debris on roadway;
(7) vehicle fire;
(8) short-term maintenance or construction lasting less than 3 days;
(9) pavement failure alert.

The information comes from a variety of traffic monitoring and surveillance systems. It is expected that by providing real-time information on special events on the oncoming road, VMS can improve vehicles' route selection, reduce travel time, mitigate the severity and duration of incident and improve the performance of the transportation network.

This study assesses the effectiveness and estimates the benefits of VMS systems using empirical data from inductive loop detectors. This study includes the following tasks:

(1) Review evaluations of the effectiveness and benefits of VMS;
(2) Define and evaluate Measurement of Effectiveness of VMS systems;
(3) Estimate drivers' response to the traffic information provided by VMS.

This study employs traffic data and incident data from the Twin Cities of Minneapolis and St. Paul, Minnesota. The conclusion in this study provides guidance on making policy about investing in VMS systems.

Few studies utilize empirical traffic data. They either use costly surveys or conduct traffic simulation, which are expensive and may not conform well to reality. This study uses empirical traffic flow and occupancy data on both mainline and ramps, collected every 30 seconds to estimate the effectiveness of VMS. The variation of diversion rate before and after warning messages is statistically tested. A discrete choice model is built to predict what proportion of the vehicles diverts to the alternative routes given the characteristics of different messages. So in this study, the effectiveness of VMS is evaluated in two ways: (1) Using a discrete choice model to estimate the response of drivers to messages provided by VMS; (2) Statistical analysis on the variation of diversion rate with and without VMS.

A before and after study allows us to quantitatively evaluate the network wide benefit of VMS systems. We define and evaluate MOE before and after installation of VMS for selected corridors. The improvement (or worsening) of traffic conditions and system performance before and after installation of VMS can be measured by these MOE terms. This study will estimate the travel time saving, safety improvement, as well as other benefits.

2. Literature Review

The existing studies for evaluating effects of VMS mainly focus on two objectives: (1) Effect of VMS on route choice guidance; (2) Effect on improving road network performance.

To test the effectiveness of VMS for route guidance, some researchers tried to estimate a route choice model for predicting how drivers respond to the information provided by VMS and whether the drivers will divert to avoid incident on road. However, the diversion behavior cannot be explained solely by external environmental factors. It also depends on the specific person in specific situations. If we don't have information about drivers' characteristics or their relevance to the message on VMS, we are unable to obtain a route choice model to predict which specific route the driver will take after receiving information from VMS.

For this reason, many researchers used costly survey or simulation to gather these data. The methods of survey used are revealed preference, and stated preference questionnaires of hypothetical situations. (Khattak 1991; Khattak, Schofer and Koppelman 1993; Wardman, Bonsall and Shires 1998; Abdel-Aty 2000; Hao, Taniguchi, Sugie, Kuwahara and Morita 1999). These studies provided valuable information on travel behavior in response to warning messages displayed on VMS. It was found that drivers are more willing to divert if there are fewer traffic stops on the alternate routes and if they are familiar with the alternate routes. In addition, young, male and unmarried drivers were more likely to divert.

Using evidence from mail survey results, the French DOT estimated that 50 percent of vehicles would divert given the choice between congested and free flowing links. Nonetheless, we believe this number is higher than the actual number of vehicles that would respond to a VMS. A number of researchers explored drivers' responses to traffic information provided by VMS. Khattak (1993) suggested the diversion behavior was influenced by the *accuracy and detailed information,* including travel times and alternate choice, and *knowledge of nature of the event* and actions to clear it in case of incidents. Yang (1993) also found that the route choice behavior was affected by the characteristics of the alternative routes. According to the investigation of effects of VMS on link flow, based on loop detector data, they found that VMS could affect vehicle diversion significantly, especially during congested times; VMS had more influence on drivers during morning peak hours than during evening peak hours; the longer the queue length posted in VMS, the more drivers diverted. Peeta (1991) found that the *location of an incident and its duration* also affected the route choice. In Virginia, surveys of driver (Benson, 1996) found *that drivers' characteristics such as* age, education, income, sex *have no significant influence on their attitude towards VMS messages.* In Dallas, 71-85% of surveyed drivers used the recommended route. The factors having influence on diversion include traffic conditions on the alternate routes, familiarity with the alternate route, confidence in the information. (Dudek 1992) (Source: http://www.benefitcost.its.dot.gov/its/benecost.nsf)

However, the drawbacks of surveys are their cost and the question is whether individuals are ready to behave in accordance with their choices in real world. Therefore, some route choice simulators are developed to gather information on drivers' characteristics and response, such as VLADIMIR (Bonsall and Merrall 1995), FASTCARS (Adler, Recker and McNally 1993). Bonsall (1995) concluded by a route choice simulator that the *clarity of the message, the distance of the VMS from the incident, the inclusion of delay time* on message influenced the diversion behavior.

Although a route choice model may provide valuable information on the effectiveness of VMS, there are still some doubts about such a simple model. One is the hypothetical assumption owing to the difficulty of obtaining data on driver behavior. The other is the simplification of models. For this reason, some research evaluated network effect on congestion after VMS widely implemented. But evaluating the impacts of VMS on network performance is difficult because of the complexity of the network systems and various developments or seasonal impacts.(Kraan, Zijpp, Tutert, Vonk, and Megen). But such studies can assess the network effect of VMS without specific data on driver behavior by comparing the network performance before and after installation of VMS.

3. Data Collection and Analysis

The VMS located at the crossroad of Little Canada Road at I-35E south bound is selected to study of drivers' response. Three Variable Message Signs newly installed in July 1999 were selected for the before and after study: the two VMS at the crossroads of the south of Lone Oak Rd and TH-77 on I-35E north bound; another VMS installed at the crossroad of I-35E on TH-77 north bound. The fourth VMS to estimate its effectiveness on TH 169 south bound which was installed in July 1996 is selected. The data collected include:

(1) Traffic volume and occupancy from loop detectors on freeways;

The traffic data for calculate the MOE of VMS were obtained from the loop detectors deployed on I-35E and TH 77 and the access ramps. The data were collected in 1999 and 2000, which includes the traffic counts and occupancy in 30 second time intervals, which were derived from loop detector data. The traffic data to estimate drivers' response to VMS were collected by the loop detectors on I-35E and the off-ramps to calculate the diversion rate. The data were collected in September 2000.

(2) Messages on VMS during September 2000;

Messages displayed on panels of 45 VMS in Minnesota in September 2000 were collected to conduct a regression analysis. The database includes the content and the start time of messages.

(3) Detailed incident log from 1991 till 2001:

An incident database was obtained from the Minnesota Department of Transportation Traffic Management Center (TMC) for the Twin Cities, which recorded detailed incident information from 1991 to 2001. This database includes the type of incident, direction and exact location of each incident, start time and clearance time of incidents, the lane closed and the number of vehicles involved.

(4) Time of installation of VMS.

There is no record of exact installation time of VMS systems. It is estimated by DOT staff that the VMS is installed around the installation time of ramp meters close to it.

4. Drivers' response to VMS

A. Discrete Diversion Choice Model

In this study, a weighted Probit model is presented to estimate the drivers' diversion behavior given the characteristics of messages and the nature and location of incidents. The factors considered to influence vehicles' diversion behavior are as follows:

- Whether alternative exit is available ahead (0-1 dummy variable);
- The nature of incident: congestion, crash, stalled vehicles or roadwork (categorical variable);
- Peak period (7:00 – 9:00 am) and non-peak period (10:00 – 20:00) (0-1 dummy variable);
- Whether the message attracts vehicles to exit at the ramp, discourages vehicles from diverting (repel), or has no influence on this route (categorical variable). (Overall there were 6 repel messages, 35 attract messages, and 3 messages with no specific effect)

The Probit function is defined as the standardized cumulative normal distribution. The model can be written as:

$$\Phi^{-1}(p_j) = \beta_0 + \beta_k x_{jk} + e_j$$

Where *p(j)* represents the probability that a driver chose to divert in response to the message. In this study, we assume that the diversion rate is stable over 5-minute intervals. Traffic data in 5-minute intervals are used to calculate the diversion rate on each exit. The dependent variable is the count of vehicles exiting at the off-ramp among the total vehicles on both the off-ramp and mainline.

Since variance of diversion rate is not constant, but correlated to the volume, we use a weighted least squares method to estimate the model with weights proportional to $n_j p_j (1 - p_j)$, where n_j represents the population for observation j, that is, the volume in one observation time slice.

The Probit choice model is estimated for the proportion of diversions at exits downstream of the VMS at Little Canada Road on I-35E. Forty-four messages in September 2000 are considered.

The observations include the flow in 5 minutes time slice on both ramps and mainline in workdays under both incident and non-incident conditions.

The systematic component of the utility included nine parameters. (i.e k=9). The results are shown in Table 1. The first coefficient is an alternative-specific *constant*, which reflects the difference in the utility of alternative i from that of j. In the model depicted above, the estimate for β_0 is negative, reflecting a relative preference for staying on the freeway without any information promoting diversion.

The second and the third coefficients correspond to whether an *alternative route* is available ahead. The third term is the interaction of an *alternative route* with whether the *message* is on. The positive sign of the second term indicates that the diversion rate at the first exit is greater than the last one without *message*. The negative sign of the third coefficient means that the probability of diversion is lower at the first exit than the last exit if the VMS indicates there is an incident ahead.

The next three terms are alternative-specific variables, which reflect the content of the message. They indicate that an *incident*, *congestion,* or *roadwork* is provided by VMS. Basically, these variables reflect the differences in preferences for response to the message or not. The coefficients for these three coefficients are all positive, which means the probability of diversion increases in response to the message of *incident*, *congestion*, or *roadwork*. The term for *roadwork* is not a significant factor. The reason is the messages collected are limited, of which only three messages indicate roadwork ahead. Moreover, all these three messages appeared within half an hour. Another important discovery here is the coefficient for *incident* is greater than the other two. This indicates that the influence of *incidents* is greater than *congestion*; both are greater than *roadwork*.

The *peak* term indicates whether the message appeared during the peak period. The coefficient is negative and significant, which means the VMS is less effective during the peak period. The reason is that traffic conditions are unstable during the peak hour and the traffic is too heavy to divert easily. Moreover, the traffic conditions are also not clear on alternative routes. The influence of incidents was reduced.

The last two terms indicate the message *attracts* vehicles to divert or shows incidents on the alternative roads and *repels* them from diverting. The positive sign of *attract* indicates that vehicles are more likely to divert to alternative routes when message displaying incident on the road. The negative coefficient of *repel* means more vehicles will choose to stay on the road instead of diverting when there are incidents on alternative roads.

This Probit choice model provides a reasonable explanation of drivers' response to messages with different characteristics. It is clear that the content of messages has a significant influence on drivers' diversion behavior.

Table 1: Weighted least squares probit estimates for grouped data

Probit	*Coefficient*	*t-ratio (p-value)*
Constant	-1.429	-34.48 (0.000)
Alternateroute	0.461	74.62 (0.000)
*Alternateroute*message*	-0.216	-8.55 (0.000)
Incident	0.156	2.54 (0.011)
Congestion	0.138	2.07 (0.038)
Roadwork	0.002	0.03 (0.980)
Peak	-0.214	-30.72 (0.000)
Attract	0.011	2.27 (0.023)
Repel	-0.089	-2.16 (0.031)
R-squared	0.7295	
Residual SS	47.8932	
Observations	2363	
Degree of freedom	2352	
Model test		F(10, 2352) = 634.36 (0.000)

B. Statistical Analysis

Statistical analysis is also used to test the difference of the diversion rate before and after a message is activated. It is expected that the vehicles will take an alternative route instead of the congested road and the number of exiting vehicles on off-ramps would change immediately after a warning message. That is to say, the diversion rate after a message should significantly increase immediately after a message warning of a special event ahead on the road. On the other hand, the diversion rate should significantly decrease immediately after a message warning of congestion or an incident on other roads. Therefore, under these two situations, the null hypothesis that the mean of diversion rate in 10 minutes before and after the message is tested respectively using t-test:

$$H_0: d_{-10} = d_{+10}$$

This analysis tests the null hypothesis that the mean diversion rate over a 10 minutes period before and after the message doesn't change. The diversion rate here is integrated in 5 minutes intervals. Messages can have two different influences on different exits, one is to attract diversion, the other is to repel diversion. So the data were grouped into two groups according to the effect of the message. The study site is the VMS of Little Canada Road on I-35E.

When the message indicates an incident on alternate route (a *repel* message), the drivers' response within different period before or after the message is summarized as follows:

Table 2: Diversion rate before and after the repel messages

Period	*Mean*	*Sd*	*Number*
Before message	0.168	0.039	23
10min after message	0.139	0.037	13
20min after message	0.139	0.045	8
30min after message	0.155	0.040	8
40min after message	0.156	0.044	8
Total	0.152	0.041	60

When the message induces diversion (we called it *attract* message), the drivers' response within different period before or after the message is summarized as follows:

Table 3: Diversion rate before and after the attract messages

Period	*Mean*	*Sd*	*Number*
Before message	0.119	0.059	191
10min after message	0.144	0.066	137
20min after message	0.128	0.059	84
30min after message	0.122	0.057	80
40min after message	0.119	0.057	76
Total	0.127	0.061	568

We perform t-test on the equality of means within different period before and after messages. From these tests, we can conclude that diversion rate within 10 minutes after the message is significantly different than that before the message. Results of tests are shown in Table 4 and 5:

Table 4: Statistical test result for the repel messages

	Difference of mean	t-statistics	Two-tailed significance
$Mean_0=Mean_{0-10}$	0.029	2.182	0.0361
$Mean_0=Mean_{10-20}$	0.029	1.718	0.0964
$Mean_0=Mean_{20-30}$	0.013	0.809	0.4254
$Mean_0=Mean_{30-40}$	0.012	0.707	0.4852

Table 5: Statistical test result for the attract messages

	Difference of mean	t-statistics	Two-tailed significance
$Mean_0=Mean_{0-10}$	0.025	-3.643	0.0003
$Mean_0=Mean_{10-20}$	0.009	-1.143	0.2547
$Mean_0=Mean_{20-30}$	0.003	-0.382	0.7030
$Mean_0=Mean_{30-40}$	0.000	0.0014	0.9989

5. Estimation of MOE to assess the benefit of VMS

A before and after study is employed to evaluate the improvement of performance on the network. The benefits of VMS are comprised of: 1) travel time saving; 2) reduction of total delay; 3) safety improvement; 4) environment improvement 5) providing information to travelers who choose not to divert. In this study, we consider the first three measurements for estimate the benefit of VMS systems.

A. Travel time savings

The chief objective of VMS is to divert traffic flow when an incident happens ahead and by encouraging vehicles to use alternative routes. Therefore, the travel time saving for drivers is one of important benefits of VMS systems.

Travel time saving can be measured as the difference of travel time before and after installation of VMS on the same freeway segments that are affected by the VMS. The situations under both incident and non-incident situations, peak period and non-peak period are considered respectively. Empirical data from loop detectors are used to calculate travel time on freeway.

The freeway is divided into small segments. Travel time on the freeway can be obtained by summing the travel time on continuous segments. Each segment includes one mainline station of loop detectors. The segments are divided by the midpoint between mainline stations, or by the ramp exit point. The time period is divided into 5 minutes time slices, and travel time is calculated for each time slice on each freeway segment.

From loop detectors, we can get traffic flow and occupancy data. Given each segment length, it is also necessary to get the space mean speed during each segment. It is a challenging problem to accurately calculate space mean speed on each segment. For simplicity, the calculation of speed is based on the following assumptions.

Assumptions:

- Traffic speed and volume data are determined from the loop detectors on the segment, and volume, speed and density in 5 minutes time slices throughout the same segment are assumed to be homogenous.
- Effective vehicle length is 22 feet.
- Speed is free flow speed (60 miles/hour) if occupancy is below 10%, and 5 miles/hour if occupancy is above 80%.

The travel time on the segments of TH-77 north bound from the location of the VMS to I-394 is compared under three situations: Situation 1 is November 1998 before installation of ramp meters and variable message signs; situation 2 is November 1999 after installation of ramp meters and variable message signs; situation 3 is during the eight-week period of ramp meters shutdown from the middle of October till the middle of December, while variable message signs still operated. Note that ramp meters only operated during the peak hours in situation 2.

Table 6: Comparison of travel time on TH-77

		Incident travel time	Non-incident travel time	Hourly Volume
Situation 1 1998 No VMS and Ramp Meters	Peak hour	658	281	4498
	Non-peak	281	258	1870
Situation 2 1999 With VMS and Ramp Meters	Peak hour	512	273	4641
	Non-peak	247	238	1899
Situation 3 2000 Ramp Meters Shutdown	Peak hour	765	431	4928
	Non-peak	320	271	1882

From the above result, we conclude that the there is a 22.2% reduction of travel time with incidents during AM peak hour after installation of both VMS and ramp meters. Similarly, during non-peak hours, travel time can be reduced by 12.1% with incidents, attributable solely to VMS, as the ramp meters in general were not operating. Under normal conditions without incidents, the travel time decreased by 6.4% after installation of VMS and ramp meters during peak hour and 7.75% during non-peak hour. However after the ramp meter shut down, it is obvious that the travel time increased again, especially during peak hour. Ramp meters are more much more significant factor in reducing peak hour travel time than VMS. In fact, there is little evidence here that VMS can improve peak hour travel time at all, as the 2000 data with VMS is always worse than 1998 data. However, hourly volume increased year-by-year especially during peak hours. Therefore, the increase on travel time may reflect an increase in traffic levels.

In case 2, the travel time on segment of I-35E from VMS to I394 is also compared in three situations as in case 1.

Table7: Comparison of travel time on I-35E

		Incident travel time	Non-incident travel time	Hourly Volume
Situation 1 1998 No VMS and Ramp Meters	Peak hour	514	421	3030
	Non-peak	488	418	1563
Situation 2 1999 With VMS and Ramp Meters	Peak hour	561	425	3246
	Non-peak	452	416	1579
Situation 3 2000 Ramp Meters Shutdown	Peak hour	680	447	3614
	Non-peak	464	437	1579

From the comparison, we find the travel time increased slightly under incident situation during AM peak hour; and saved 7.38% during non-peak hour with incident after installation of VMS and Ramp meters. Under non-incident situation, the travel time didn’t decrease during peak hour. After ramp meter shut down, it is shown once more that the travel time increases, especially during peak hour. However, at this location, VMS does save freeway travel time with incidents in the peak hour. Also, in this case, hourly volume increases year-by-year during peak hours. Therefore, the increase on travel time is also partly caused by increase traffic levels.

B. Reduction of total delay (vehicle-hours saving)

Vehicle-hours reduction per incident is measured to evaluate the benefit of VMS on reduction of total delay. In this section of the report, input and output analysis is used to calculate the total delay, that is, vehicle-hours in queue. A queuing diagram explains the formation and clearance of the queue, and the delay time in queue. When an incident happens, the capacity of road reduces and the queue begins to stack at the bottleneck when the arrival rate is over the reduced capacity. The vertical difference of two curves is the length of queue at a specific time and the horizontal distance between two curves is the delayed time in queue. Therefore, the total delay can be calculated as the area between the input and output curve.

The freeway is divided into small segments as in the calculation of travel time. Each segment includes one mainline station of loop detectors. The segments are divided by the midpoint between mainline stations, or by the ramp exit point. If some loop detector in a certain segment is bad, the segment is split between two adjacent segments. The criterion for determining bad detectors is an occupancy over 80% or zero flow. In space and time domain, the time period is divided into 1-minute time slices, and traffic flow and speed are calculated for each time slice on each freeway segment.

VMS provides dynamic information about incidents to drivers and increases the rate at which drivers divert at the exits before incident location. Theoretically, after VMS is turned on, the arrival rate decreases (assuming the VMS is warning of a message ahead on the same road. From the Figure 1, we can see the duration for queue dissipation reduce. So both the queue duration and the number of vehicles involved in the queue are less than without VMS, which results in reduction of the total vehicle-hours delay caused by incident. Therefore, the difference of the area between the input and output curve is the reduction of total delay in vehicle-hours.

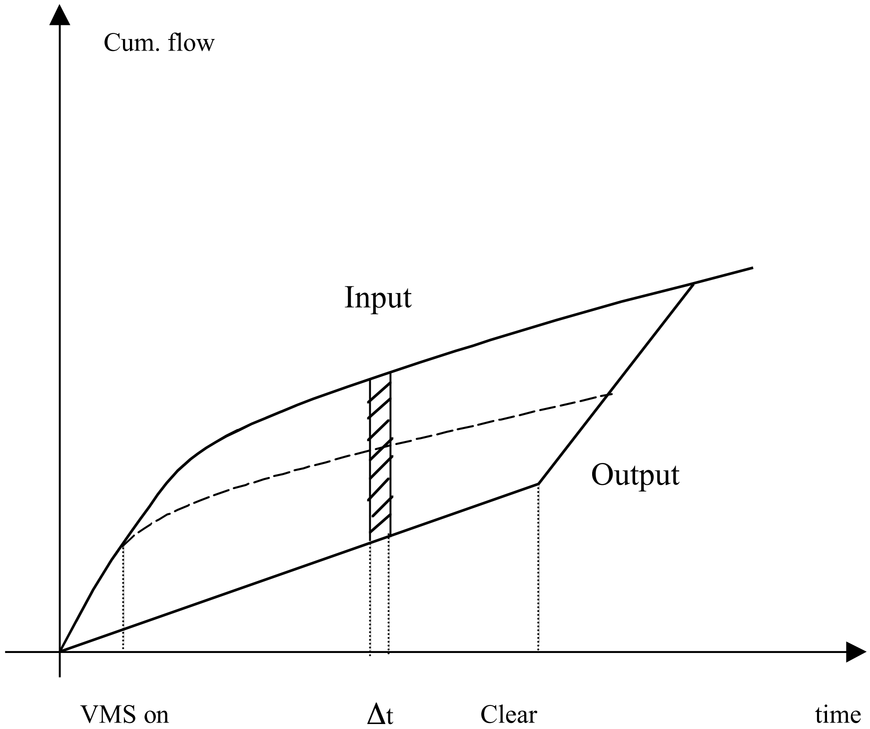


Fig. 1. Input and Output diagram

Total delay in vehicle-hours can be calculated as follows:

Total Delay time: $D(t_n) = D(t_{n-1}) + (t_n - t_{n-1})(I_n - O_n)$

Average delay: $\overline{d} = D(t_n) / \sum_{n=1}^{T/\Delta t} (\lambda_n - \mu_n)$

Where

I_n is the cumulative arrivals at time slice n.

O_n is the cumulative departures at time slice n.

λ_n is the arrival rate at time slice n.

μ_n is the departure rate at time slice n.

T is the incident duration.

It is necessary to know the cumulative arrival rate, cumulative departure rate and duration of incidents for calculating the total delay for each incident. By comparing the difference of average vehicle-hours per incident before and after installation of VMS, the effectiveness of VMS in incident management can be measured.

Assumptions:

- In the input and output method, the queue doesn't begin to form until the arrival rate exceeds capacity.
- This method estimates a queue formed at one single point and assume that vehicles are vertically stacked.

The reduction of total delay of vehicle-hours is calculated before and after installation of VMS on TH-169 southbound. Vehicle-hours savings due to VMS are calculated incidents in the peak and non- peak periods.

Table 8: Reduction of total delay before and after VMS

Total Delay (Vehicles-minutes)	After VMS and RM	Before VMS and RM
Peak period	19868	27990
Non-peak period	8226	11860

On average, VMS and Ramp meters can reduce total delay up to 136 vehicle-hours per peak period incident and 60 vehicle-hours per incident during non-peak period.

C. Safety improvement

VMS can help to reduce the duration and severity of congestion, which result in the reduction of occurrences of crashes. The variation of average number of crashes on each segment is considered as the measurement of safety improvement.

The number of incidents happened in three situations as before on I-35E and TH-77 are compared as follows:

Table 9: The number of incidents on freeway 35E

Number of incidents	Situation 1	Situation 2	Situation 3
Crash	25	41	66
Stall	19	12	29
Rollover	2	0	0
Other	2	5	6

Table 10: The number of incidents on TH-77

Number of incidents	Situation 1	Situation 2	Situation 3
Crash	5	5	12
Stall	5	8	9
Spinout	0	1	0
Other	0	0	1

It can be found that incident frequency increase year by year despite the installation of ramp metering and VMS on I-35E and TH-77. Therefore, data were not sufficient to demonstrate a safety improvement considering only the number of incidents.

6. Conclusion

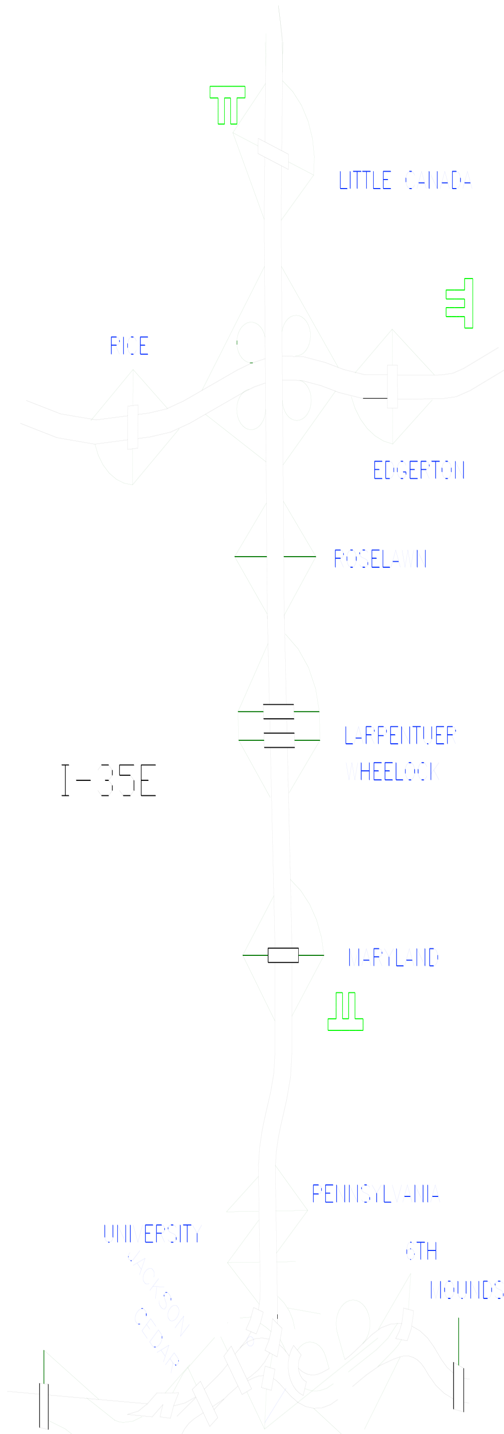
The effectiveness of VMS on route guidance is assessed by a discrete probit choice model and statistical test using empirical traffic flow and occupancy data from loop detectors on both mainline and ramps, collected every 30 seconds. The difference of diversion rate before and after warning messages is statistically tested. The discrete choice model estimates the proportion of vehicles that diverts to an alternative routes given the characteristics of different messages.

The result of the statistical analysis shows that VMS is an effective tool in route guidance and can increase drivers' diversion rate significantly by providing warning messages about the traffic conditions on the road. The probit choice model provides a reasonable explanation of drivers' response to messages with different characteristics. The nature of the incidents is a factor to influence the diversion behavior. Incidents warned by the message have greater influence than congestion; both have greater influence than roadwork. VMS is more effective in light traffic than heavy traffic. This may be because it is difficult to change lanes, merge or divert in heavy traffic. Alternatively, it may be due to congestion on alternatives during times of heavy traffic. Drivers prefer to start to divert at several exits prior to the incident.

A before-after study is also conducted to quantitatively evaluate the network wide benefit of VMS systems. We defined three measurements of effectiveness: travel time savings, vehicle-hours reduction per incident and safety improvement to evaluate the benefit after installation of VMS systems. From the results, we see that VMS has no obvious effect on reduction of travel time. It is shown that VMS and ramp meters on TH-77 can help reduce travel time together for vehicles. But during the ramp meter shut-down, the travel time increased again. It indicated that the ramp meters are more effective in reducing travel time. But this also reflects an increase of traffic levels. On 35E both ramp meters and VMS are less effective in reducing travel time. After ramp meters shut down, the travel time increased again. Tests on TH-169 demonstrate that VMS and ramp meters together can reduce the total delay up to 136 vehicle-hours per peak period incident and 60 vehicle-hours per incident outside the peak period. The number of incidents on both TH-77 and I-35E increased despite VMS and ramp meters, thus we provide no evidence to the hope that VMS can help to improve safety.

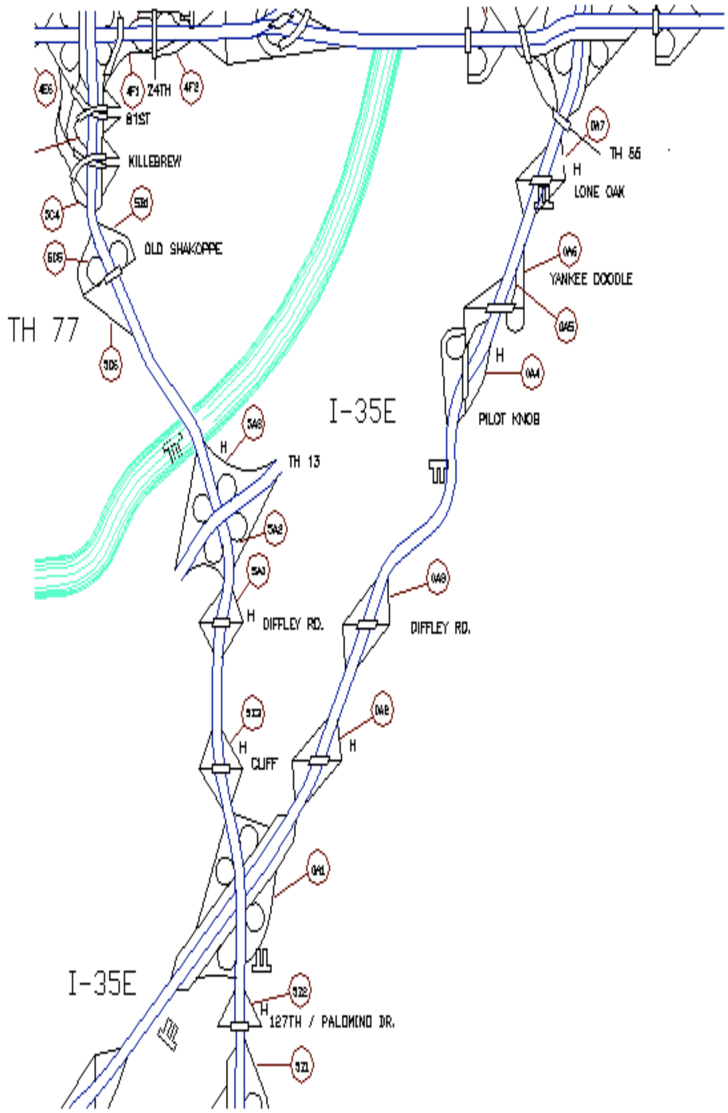
In future studies, the optimization of VMS systems is suggested to make further study for deploying new VMS systems. VMS effects vary by location. Therefore, with finite budgets, it is important to choose effective locations to deploy VMS systems. The content displayed on VMS is also an influential factor on the effectiveness of VMS. Further study on how to design the messages more effectively is also suggested.

Appendix1: Study site 1: VMS at the road of Little Canada on Freeway 35E south bound

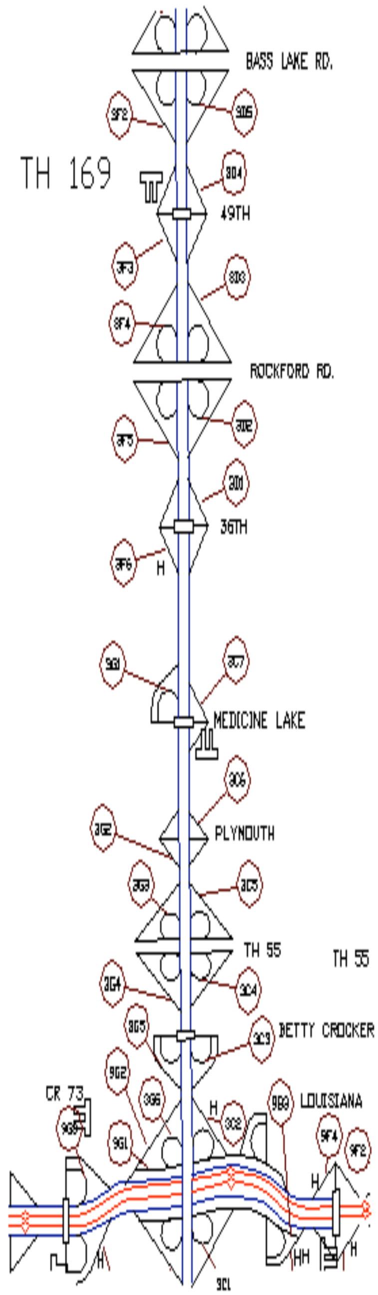


Appendix2: Study site 2: VMS at the south of Lone Oak Rd on I-35E north bound

Study site3: VMS at the north of Minnesota River on the TH-77 north bound



Appendix3: Study site 4: VMS at the Medicine Lake Rd on TH-169 south bound



Reference:

1. A.J. Khattak , J. L. Schofer & F. Koppelman (1993), Commuters' Enroute Diversion and Return Decisions: Analysis and Implications for Advanced Traveler Information Systems, *Transpn. Res.*-A, Vol. 27A, No.2, pp.101-111.
2. M. Wardman P. Bonsall & J. Shires (1998), Driver Response to Variable Message Signs: A Stated Preference Investigation, *Transpn. Res.-C*, Vol.5, No.6, pp389-405.
3. Mohamed A. Abdel-Aty (2000), Using ordered probit modeling to study the effect of ATIS on transit ridership. *Transpn. Res.*-C 9, pp 265-277.
4. E. Hao, M. Taniguchi, Y. Sugie, M. Kuwahara and H. Morita (1999), Incorporating an information acquisition process into a route choice model with multiple information sources, *Transpn. Res.*-C 7, pp 109-129, 1999.
5. P. W. Bonsell, A.C. MERRALL(1995), Analysing and Modeling the Influence of Roadside Variable Message Displays on Drivers' Route Choice, *7th WCTR*, Sydney,1995.
6. J.l. Adler, w. W. Recker & M. G. McNally, (1993) A conflict model and Interactive Simulator (FASTCARS) for predicting enroute driver behavior in response to real-time traffic condition information, *Transportation 20*, pp 83-106.
7. M. Kraan, B. Zijpp, B. Tutert, T. Vonk, & D. V. Megen, Evaluating Networkwide Effects of Variable Message Signs in the Netherlands, *Transportation Research Record 1689*, Paper No. 99-1126.
8. Makigami, Y., and Woodie, W.L. Freeway Travel Time Evaluation Technique. *Highway Research Record 321*, HRB, National Research Council, Washington D.C., 1970, pp. 33-45.
9. Messer, C.J. and Dudek C.L., Friebele J.D. Method for Predicting Travel Time and Other Operational Measures in Real-time During Freeway Incident conditions. *Highway Research Record 461,* TRB, 1973, pp. 1-16.
10. Youngbin Yim & J. Ygnace, Link Flow Evaluation Using Loop Detector Data: Traveler Response to Variable-Message Signs, *Transportation Research Record 1550*, pp. 58-65.
11. Morales, J.M., Analysis Procedures for Estimating Freeway Traffic Congestion. *Public Road*, vol. 50, No.2, September 1986, pp. 55-61.

12. Olmstead, Todd, Pitfall To Avoid When Estimating Incident-Induced Delay by Using Deterministic Queuing Models, *Transportation Research Record 1683*, 1998, pp. 38-46.

13. Al-Deek, H., Garib, A. and Radwan, A.E., New Method for Estimating Freeway Incident Congestion, *Transportation Research Record 1494*, pp. 30-39.

14. Wirasinghe S.C., Determination of Traffic Delays from Shock-Wave Analysis, *Transportation Research, vol.12*, pp. 343-348.

15. Chow W.M, A Study of Traffic Performance Models Under An Incident Condition, *Highway Research Record 567*, HRB, National Research Council, Washington D.C., 1974, pp. 31-36.

16. Thill J.C., Rogova G. and Yan, J. Delay Modeling for Corridor-level Benefits Evaluation of VMS deployments, paper presented at *the 2001 Annual Meetings of Transportation Research Board,* 2001.

17. http://www.benefitcost.its.dot.gov/its/benecost.nsf