STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV. 10/98)

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
CA10-1051	50853	UCB-ITS-CWP-2009-4

4. TITLE AND SUBTITLE	5. REPORT DATE / 6. PERFORMING ORGANIZATION CODE
Effectiveness of Information and Control ITS Field Elements on Commuter Trips	September, 2009
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Ali Mortazavi, Xiaohong Pan, Lianyu Chu, Zhen Sun	UCB-ITS-CWP-2009-4
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NUMBER
California Department of Transportation Division of Research and Innovation, MS-83 1227 O Street Sacramento CA 95814	193 11. CONTRACT OR GRANT NUMBER 77664
12. SPONSORING AGENCY AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
California Department of Transportation Sacramento, CA 95819	4/1/2007 – 9/30/2009 14. SPONSORING AGENCY CODE

15. SUPPLEMENTAL NOTES

16. ABSTRACT

There have been many Intelligent Transportation Systems (ITS) elements deployed on highways to efficiently manage traffic, alleviate congestion, and improve safety. However, transportation management agencies are lacking systematic methodologies to identify commuters' needs and perception regarding ITS elements. In addition, there are few reliable tools and performance measures that can assess the effectiveness of those elements on commuters and travelers. This research project intends to address these problems by analyzing both tangible and intangible benefits of information and control field elements and assessing their overall impact on commuters. The CCIT research team used a commuter survey to measure intangible benefits; and conducted a micro-simulation method to evaluate quantitatively the effectiveness of traffic-information-related field elements such as CMS and 511/HAR. The final outcome of the research will place more emphasis on the effectiveness of ITS field elements to help commuters and it will recommend optimal ways in which traffic operators like the California Department of Transportation (Caltrans) can leverage the deployment of ITS field elements to improve their operational management.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Effectiveness of ITS field elements, driver behavior, traffic diversion, survey analysis, micro-simulation	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASSIFICATION (of this report)	20. NUMBER OF PAGES	21. PRICE
Unclassified	125	N/A

CALIFORNIA CENTER FOR INNOVATIVE TRANSPORTATION
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Effectiveness of Information and Control ITS Field Elements on Commuter Trips

Dr. Ali Mortazavi, Senior Development Engineer, CCIT

CCIT Final Research Report
UCB-ITS-CWP-2009-4

This work was performed by the California Center for Innovative Transportation, a research group at the University of California, Berkeley, in cooperation with the State of California Business, Transportation, and Housing Agency's Department of Transportation, and the United States Department of Transportation's Federal Highway Administration.

September 2009

ISSN 1557-2269

CALIFORNIA CENTER FOR INNOVATIVE TRANSPORTATION
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Effectiveness of Information and Control ITS Field Elements on Commuter Trips

September, 2009

Prepared by:
Ali Mortazavi
Xiaohong Pan
Lianyu Chu
Zhen Sun

CCIT Final Research Report
UCB-ITS-CWP-2009-4

For:

CALIFORNIA DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH AND INNOVATION

california center for innovative transportation
UNIVERSITY OF CALIFORNIA, BERKELEY

ISSN 1557-2269

The California Center for Innovative Transportation works with researchers, practitioners, and industry to implement transportation research and innovation, including products and services that improve the efficiency, safety, and security of the transportation system.

1 DISCLAIMER STATEMENT

This document is disseminated in the interest of information exchange. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This publication does not constitute a standard, specification or regulation. This report does not constitute an endorsement by the Department of any product described herein.

For individuals with sensory disabilities, this document is available in Braille, large print, audiocassette, or compact disk. To obtain a copy of this document in one of these alternate formats, please contact: the Division of Research and Innovation, MS-83, California Department of Transportation, P.O. Box 942873, Sacramento, CA 94273-0001.

2 PROJECT FACTSHEET

Title:	Effectiveness of Information and Control ITS Field Elements on Commuter Trips
Sponsor:	Caltrans Division of Research and Innovation
Executing Organization:	California Center for Innovative Transportation 2105 Bancroft Way, Berkeley, CA 94720 Phone: (510) 642-4522. Fax: (510) 642-0910
Execution Period:	4/1/2007 – 9/30/2009
Contract Amount	$154,180
Principal Investigator:	Professor Samer Madanat, Civil and Environmental Engineering Department, UC Berkeley
Center Director:	Thomas H. West, Executive Director, CCIT
Project Manager:	Ali Mortazavi, Senior Development Engineer, CCIT
Administrative Officer:	Coralie Claudel, Contracts and Grants Analyst, CCIT
Additional Researchers:	Xiaohong Pan, Assistant Development Engineer, CCIT Lianyu Chu, Research Engineer, CCIT Zhen Sun, Graduate Student Researcher, CCIT

Table of Contents

List of Figures

Figure **Page**

List of Tables

3 ACKNOWLEDGEMENTS

The project team warmly thanks, in no particular order, the following people who invaluably helped the project by committing their time and knowledge. Anyone who may have been forgotten additionally receives our deep apologies.

- **Fred Yazdan** and **Paul Mazdiyasni** at Caltrans DRI
- **Diana Gomez** and **Mike Jenkinson** at Caltrans HQ Traffic Operations
- **Christopher Burke** at SANDAG Mobility Management

This work was supported by Caltrans Division of Research and Innovation.

4 EXECUTIVE SUMMARY

There have been many Intelligent Transportation Systems (ITS) elements deployed on highways, and more new features have emerged on existing field elements. These new elements tend to efficiently manage traffic, alleviate congestion, and improve safety. However, transportation management agencies are lacking systematic methodologies to identify commuters' needs and perception regarding ITS elements. In addition, there are few reliable tools and performance measures that can assess the effectiveness of those elements on commuters and travelers. This research project intends to address these problems by analyzing both tangible and intangible benefits of information and control field elements and assessing their overall impact on commuters. The final outcome of the research will place more emphasis on the effectiveness of ITS field elements to help commuters and it will recommend optimal ways in which traffic operators like the California Department of Transportation (Caltrans) can leverage the deployment of ITS field elements to improve their operational management.

The CCIT research team used a commuter survey to measure intangible benefits. The survey data (conducted through SANDAG 511) shows that a majority of survey respondents have seen or heard of selected en-route information and control elements, i.e. changeable message signs (CMS), 511 traveler information system, Highway Advisory Radio, and ramp meters. Among the different elements studied, CMS and ramp metering had attained the most exposure. In general, commuters are unlikely to take an alternate route, and they tend to stay on their usual commute route even after getting traffic delay information. But there were many survey respondents who stated that they would be willing to take an alternate route in the situation of significant traffic delay. This result shows that commuters would be very responsive to ITS elements if provided with more tangible benefits, i.e. travel-time or financial saving.

The last part of the study focuses on the use of a micro-simulation method to evaluate the effectiveness of traffic-information-related field elements such as CMS and 511/HAR. The I-880 corridor is the study site. A well-calibrated I-880 Paramics simulation model was used to simulate different diversion scenarios under the occurrence of an incident during the morning peak period. Simulation results show that both CMS-based diversion and 511-based self-diversion are effective to improve system level performance and efficiency, relieve congestion, increase bottleneck capacity, and reduce emission and energy consumption.

5 INTRODUCTION

Intelligent Transportation Systems (ITS) include various freeway information and control field elements meant to better manage traffic, alleviate severe congestion, and improve safety. With more new ITS elements deployed in the field and more new features added to existing field elements (e.g., the 511 system and CMS travel time messages), there is an emergent need to conduct a thorough and concrete study on the effectiveness of various information and control field elements on commuter trips.

Our research project addresses this issue by considering information and control field elements as a whole to assess their overall impact on commuters. We will recommend optimal ways by which traffic operators like Caltrans can leverage the deployment of ITS field elements and improve operational management of these elements. The definition of field elements is limited to CMS, 511 traveler information service, and Highway Automated Radio (HAR).

Field elements such as CMS, 511, and HAR can potentially benefit commuters on their daily travels. Timely information also has the added benefit of relieving commuters of some of the stress caused by traffic congestion. Nevertheless, how commuters react to the field elements, including the general feeling that they are useful, and a propensity to alter their departure times or divert their routes, defines the effectiveness of these field elements.

In general, benefits of ITS field elements can be categorized as either tangible or intangible. Tangible benefits usually can be directly observed and possibly quantified; intangible benefits generally cannot be quantified but are nonetheless real and potentially significant. Therefore, this project will employ two parallel approaches: appraising tangible and intangible benefits. Because measuring tangible benefits from empirical data only is not realistic, we will use modeling and simulation. We propose to leverage existing literature and models of commuter response to field elements. Additionally, through a commuter survey and other techniques, intangible benefits will be reviewed and assessed in order to provide practitioners with a full operational picture of the advantages of deploying more field elements.

The final outcome of the research project will be an attempt to generalize the findings into a summary of field elements benefits, both quantitative and qualitative. Accordingly, recommendations regarding further deployment of field elements, and how to best operate them, will be formulated in practical terms to help Caltrans districts in their decision-making and day-to-day practice.

In the next section of the report, a literature review is conducted, which is followed by conceptual framework and methodology. Results and key findings of the commuter travel survey and simulation are then presented respectively. Finally, conclusions and recommendations are discussed.

6 BACKGROUND AND LITERATURE REVIEW

A comprehensive literature review was conducted. There were several goals for the literature review:

- Understanding the current practice of information and control ITS field elements
- Exploring existing evaluation measures and methods for different ITS field elements

Please see Appendix I – Expanded Literature Review for more detail.

6.1 CURRENT PRACTICE

Over the last several decades, common practices of information and control ITS field elements have been continuously promoted around the entire U.S., mainly due to the increasing demand but limited capacity of the transportation system. Table 6-1 shows the national summary of ITS deployments in 2006, which presents a comparison of how the various types of field elements have been deployed throughout the country.

Table 6-1: 2006 ITS Deployments – National Summary (108 metropolitan areas surveyed)

Freeway Management	Reported	Total	Percent
Miles under electronic surveillance	7288	19470	37%
Ramps controlled by ramp meter	4102	26336	16%
Miles under lane control	956	19470	5%
Number of Dynamic Message Signs	3398	N/A	N/A
Miles covered by Highway Advisory Radio	4004	19470	21%

Note: Highlights from the 2006 Deployment Tracking Database
Source: http://www.itsdeployment.its.dot.gov/FactSheet.asp

In this study, information and control ITS field elements are primarily defined as:

- Changeable Message Signs (CMS, fixed or portable);
- Highway Advisory Radio (HAR);
- Call-in portion of 511 travel information service (providing en-route traveler information);
- Additionally, Ramp Metering is also considered for some cases.

6.1.1 CHANGEABLE MESSAGE SIGNS

CMS, also called Dynamic Message Signs or Variable Message Signs, can be effective tools in sharing real-time traffic information with the motoring public, allowing travelers to make better route decisions, and alleviating travelers' traffic stress. Generally, CMS can display several different types of messages, primarily based on the needs and goals of the traffic operations of the regions. For instance, CMS can display:

- Traffic information and travel times;
- AMBER Alerts and safety messages;
- Homeland security information.

Dudek has organized four main categories in which CMS are used in traffic management (1):

- Recurring problems, including everyday situations, such as peak traffic congestion, and planned traffic disturbances, such as special events;
- Nonrecurring problems, e.g., incidents, accidents, temporary freeway blockages, and maintenance;
- Environmental problems, including rain, ice, snow, and fog; and
- Special operational problems (e.g., the operation of directional lanes, tunnels, bridges, tollbooths, and weigh stations, etc.).

CMS have been widely deployed throughout the U.S., as shown in the chart below (Figure 6-1), which presents the increasing rate of CMS deployment in the U.S.

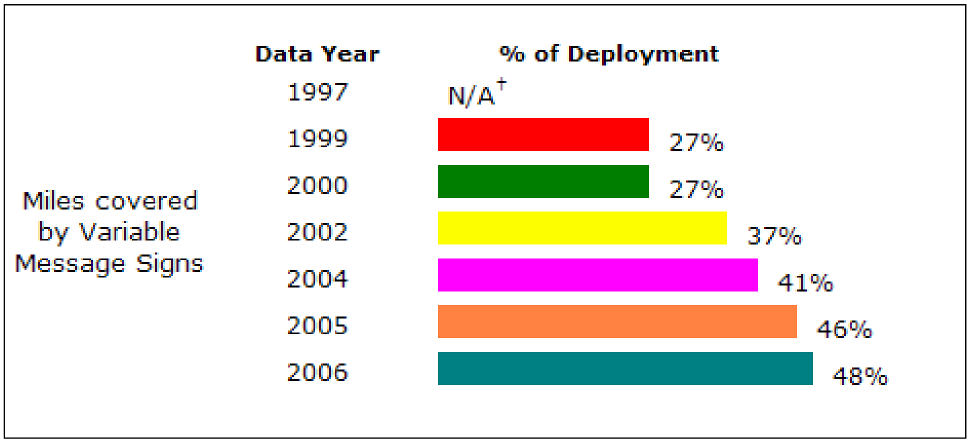


Figure 6-1. CMS Deployments by miles covered

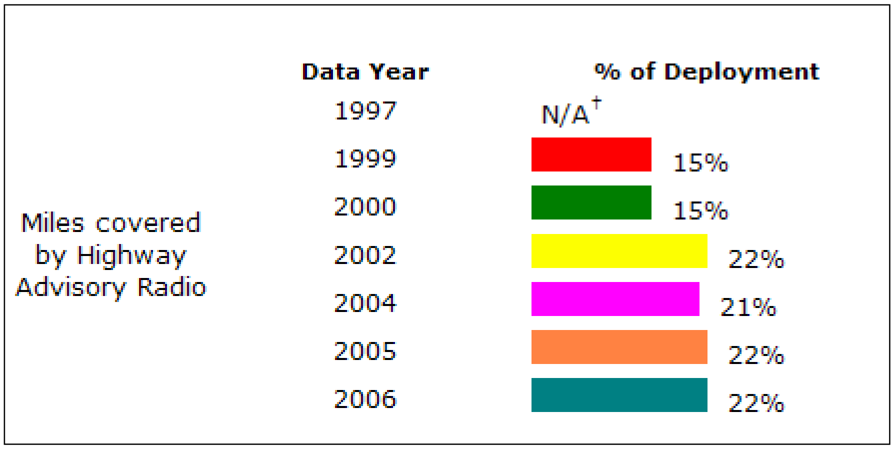
Source: http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

6.1.2 HIGHWAY ADVISORY RADIO

Highway Advisory Radio (HAR) has been used to notify the motoring public about travel hazards or other travel information (2). HAR uses AM radio frequencies that transmit between 1 and 6 miles in distance (2). It can be used to notify motorists of travel times, incidents, congestion, and special events. In detail, Highway Advisory Radio informs travelers of (3):

- Detours;
- Operating restrictions such as requirements to put on snow tires or chains;
- Warnings about hazards such as forest fires, floods, mudslides, or highway closures;
- Traffic conditions along short segments of specific routes, especially work zones;
- Directions to tourist attractions;
- Parking availability;
- Public transit alternatives;
- Notices of events.

In a 2006 national survey, it was found that HAR is deployed in 63 urban areas, yet only covered 22% of the freeway miles within those areas (4), as shown below in Figure 6-2.



Source: http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

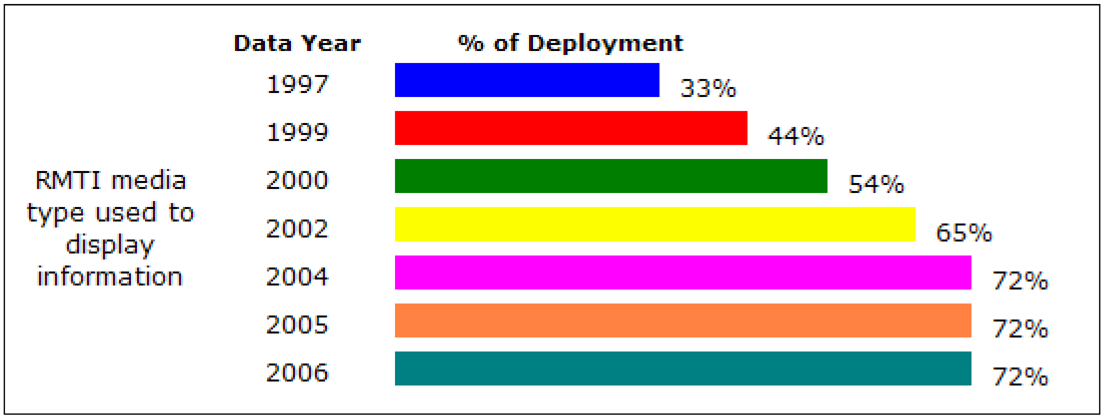
Figure 6-2. HAR Deployments by Miles Covered

6.1.3 511 TRAVELER INFORMATION SERVICES

A recent innovation in traveler information services is 511, a national three-digit telephone number designated exclusively for traveler information. The 511 Deployment Coalition was established in early 2001 to facilitate nationwide development. And as of March 2007, thirty-four 511 services in 30 states are operational (5).

511 has been used for both pre-trip and en-route information through telephone and Internet service. Source: http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=RMTI

Figure 6-3 tracks how these deployments have grown over time.



Source: http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=RMTI

Figure 6-3. Deployments of Regional Multimodal Traveler Information (511)

6.2 EVALUATION OF CURRENT PRACTICE

6.2.1 ITS FIELD ELEMENTS EVALUATION CONSIDERATIONS

Prior to initiating any performance evaluation, many factors should be considered to shape the overall evaluation (6). Thoughtful consideration of these factors will better ensure that the evaluation results are relevant to the objectives, technically valid, and appropriate to the intended audience.

6.2.1.1 TYPES OF APPLICATIONS

It is necessary for researchers and practitioners to consider different types of ITS field element applications before and during the evaluation process (7). The reason is that there are various applications even for a single type of ITS field element; different applications might have different effects on both individual travelers and on the whole transportation system. For instance, the benefits of CMS may vary between disseminating travel time information and incident information. Therefore, different evaluation measures/methods would be required for different types of applications (i.e., to assess different associated benefits).

6.2.1.2 TYPES OF ROAD USER GROUPS

Before starting the ITS field elements evaluation process, it is very important to understand travel behaviors and characteristics associated with different types of road user groups. For instance:

- Different types of road users might have different responses to similar information provided by ITS field elements because of their particular travel behaviors and circumstances (8).
- Different types of vehicles may also have particular impacts on different traffic conditions, such as incident-induced congestion.
- Network performance imposes different costs on different types of road users.

In other words, instead of isolating the effort only to the commuter side during the course of modeling, developing, and evaluating ITS field elements, it will also be worthwhile to take into account other types of user groups when possible.

6.2.1.3 STUDY AREA OF EVALUATION

Another consideration that should be addressed before moving to the evaluation process is the identification of the study area. There are obviously different goals and various levels of traffic intensity that are appropriate for the usage of ITS field elements in different areas. Therefore, the benefits of information and control ITS field elements will vary depending upon not only the intended use of the elements but also on its location (e.g., urban or rural, local or regional, etc.). Based on the purpose and extent of the study, as well as other factors like data/resource availability, analysis tool availability, the study area could be generally classified into three categories: localized, corridor, or regional (6).

In our study, we will address this consideration by first discussing the common issues and general principles of information and control ITS field elements evaluation with a broader and regional view; then we will select several study areas to do the detailed localized or corridor analysis.

6.2.2 PERFORMANCE MEASURES

There are several different categories of performance measures that have been defined by the FHWA, National ITS Architecture (9), as well as by many researchers and practitioners, for ITS field element evaluation purposes (7). Some of them are cited as follows:

- **Safety** is generally measured through changes in the number of crashes or incidents, segmented by severity or type (e.g., fatal/injury, accidents/disablements, etc.).
- **Mobility** is typically measured as a change in travel time, speed, or delay, etc. These metrics intend to capture road users' travel experience, as well as the transportation network performance.
- **Throughput** is used to represent the transportation network performance from the system operator's perspective and typically includes measures such as throughput (vehicle or person volumes), volume to capacity (V/C) ratio, queuing measures (length and frequency), bottleneck, level of service (LOS), etc.
- **Travel Time Reliability** is one of several innovative performance measures that have recently been developed. These performance measures are very important because more reliable travel time estimates allow travelers to better budget their travel schedules and eliminate the impact of expected and unexpected delays.
- **Environmental** performance measures used in ITS field elements evaluation typically contain changes in vehicle emissions, fuel consumption, and so on.
- **Public Perception/Acceptance** represents the perceptions of travelers regarding the effects of the ITS field elements and their acceptance of the system performance, which can be extremely important measurements depending on the purpose of the study.

Based on the different categories of performance measures discussed above, as well as on an understanding of the goals of the system, we will establish a comprehensive set of performance measures in our study.

6.2.3 EVALUATION METHODS

With appropriate performance measures selected, the benefits of ITS field elements can be evaluated through various evaluation methods. Benefits can usually be categorized as either tangible or intangible. When tangible benefits can be directly observed and possibly quantified, a quantitative method should be employed. Intangible benefits generally cannot be quantified but are real and potentially significant, e.g., traffic stress. Therefore, a qualitative method might be used to measure intangible benefits.

6.2.3.1 QUALITATIVE METHODS

For transportation researchers and practitioners, the study of information and control ITS field elements is motivated by the human propensity to modify behavior to suit new conditions (10). Understanding traveler behavior is important for developing and evaluating ITS field elements; however, it usually requires analytical skills within the qualitative fields.

According to existing literature, since it is expensive and difficult to design, conduct, and control the observation study in the real world, researchers are using experimental approaches to evaluating travel behavioral responses (11). Some measures could be typically evaluated through a series of one or more focus group interviews, telephone surveys, or panel surveys. Relying on qualitative methods as well as the descriptive and inferential statistic analysis techniques, several considerations of potential behavior causal factors should be addressed (11) in the evaluation process, such as:

- How do people perceive information and control ITS field elements?
- How do travelers use the dynamic traffic information and control that they acquire?
- Why is dynamic traffic information and control important for travelers?
- What are the consequences of using ITS field elements?

6.2.3.2 QUANTITATIVE METHODS

many studies using quantitative methods have pointed out that providing dynamic traffic information and control (essentially via ITS field elements), could offer significant benefits to ameliorate traffic congestion, improve network performance, and enhance travel safety, thus providing economic and environmental advantages, etc. (12-14).

Within the research using quantitative methods, few studies use empirical traffic data because of the difficulty of data collection. Hence, due to the scarcity of field data, and the considerable higher cost associated with observational field study, researchers and practitioners have modeled them in laboratory experiments and through simulations. Examples of simulation tools that have been used for ITS field elements evaluation include IDAS, DynaMIT, DYNASMART-P, INTEGRATION, PARAMICS, etc (15-19).

6.2.3.3 RELATIONSHIP BETWEEN QUALITATIVE AND QUANTITATIVE METHODS

Using conceptual models of the behavioral choices travelers' who have received traffic information and control is an efficient way to establish the relationship between qualitative and quantitative evaluation methods,.(12-14).

Accounting for traveler behavior is a critical aspect in evaluating traffic information and control ITS field elements. Several relevant studies have already conducted simulation models or proposed theoretical frameworks with consideration of behavioral characteristics (12, 20-24). However, there remains a weak connectivity between drivers' actual responses to traffic information/control and system performance modeling tools. Therefore, how to effectively design and conduct a qualitative study (i.e., behavioral survey analysis), as well as how to incorporate results from qualitative study into quantitative study (i.e., simulation analysis) is an interesting issue to analyze.

7 METHODOLOGY

7.1 INITIALLY PROPOSED CONCEPTUAL FRAMEWORK

This research project aims to develop methodologies to study the effectiveness of ITS information and control field elements. The following conceptual framework was first proposed based on the project scope and findings from literature (as shown in Figure 7-1).

- In the first step, we will conduct a comprehensive review on existing literature (also with Caltrans practitioners' inputs) to discover the current practices of ITS field elements (e.g., applications, costs and benefits, barriers), as well as to explore various performance measures and evaluation methods used for understanding motorists' travel behaviors and assessing effectiveness of ITS field element.
- Based on the review results, we will design effective performance measures and evaluation methods to investigate the benefits (intangible and tangible)of field elements considering the constraints associated with the project.
- A commuter survey will be created, distributed, and analyzed. The survey is not only for collecting intangible benefits but also for providing inputs to a commuter response model based on motorist's travel behavior. The flow chart of commuter survey questionnaire design is attached in Chapter 8.
- Travelers/commuters face different types of travel conditions (e.g., normal, recurring peak-hour congestion, non-recurring incidents/work zone), where the effect of ITS field elements may be different. Therefore, we propose different scenarios to reflect various traffic conditions. For instance, for non-recurring congestion situations, we will rely on the commuter route choice model and the simulation tool to identify the associated tangible benefits. To be more specific, the commuter route choice model is formulated through the inferential statistical analysis of commuter survey data, in which various factors are taken into account, such as, route choice behavior, travel contexts, characteristics of field elements, and so on.
- Finally, in the results of the analysis, qualitative and quantitative benefits will be generalized and policy application for Caltrans practitioners will be formulated accordingly.

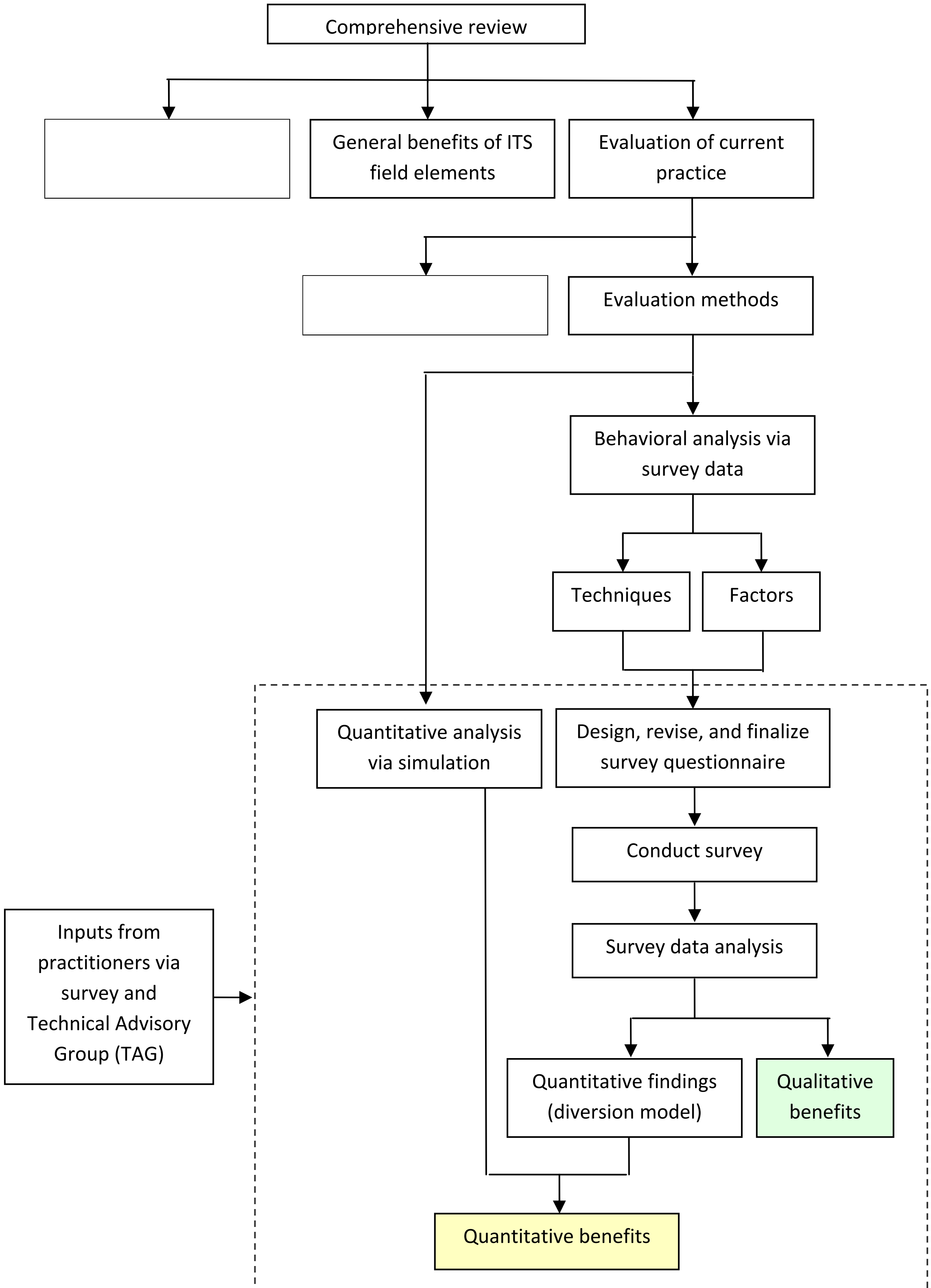


Figure 7-1. Conceptual framework for effectiveness of information and control ITS field elements on commuter trips

7.2 UPDATES ON CONCEPTUAL FRAMEWORK

Although we proposed two objectives for the commuter travel survey, only one can be achieved in our later survey experiment, which is to understand intangible benefits of information and control ITS field elements by exploring commuters' perception on those elements. But the second objective – generating commuter response model based on motorist's travel behavior – could not be fully managed, mainly due to limited sample size that we could collect via our only available survey distribution channel. In response to this significant limitation of survey results, we revised the related part of research methodology and designed new approaches to test and identify possible tangible benefits of selected elements.

In particular, we conducted a literature review to understand the general market penetration rate and the diversion rate of different ITS field elements. Then, these general rates, combined with specific rates based on our context sensitive survey results, were all considered in the later commuter travel simulation experiments to indentify tangible benefits of information and control ITS field elements. These replaced the initially proposed work plan of generating a commuter response model utilizing travel behavior collected via a commuter travel survey.

Detailed discussion about possible market penetration rate and diversion rate of information and control ITS field elements are presented as follows.

- Market penetration rate
  - The market penetration rate of traveler information can be affected by many issues, such as the availability and accessibility of various information resources around the region, travelers' acceptance level of different travel information, etc.
  - According to a nationwide survey conducted by ITS JPO in 2006, there has been 48% of miles covered by CMS, 22% of highway miles covered by HAR, and 72% of major metropolitan areas covered by 511 (25).
  - In some regions in the U.S. travelers are less likely to utilize travel information, but the market penetration rate in California is much higher than that of others. This is facilitated by the proactive ITS deployment and traffic management efforts conducted by Caltrans, as well as by behavioral patterns of California travelers themselves. For instance, a 2005 Bay Area survey returned a percentage of 84% of respondents who always or often noticed CMS (26).
  - Our survey results also yielded reasonably high market penetration rates for different information and control ITS field elements, i.e., 89% for CMS, 20% for HAR, 47% for 511, which could be references for suggested market penetration rates in the later simulation experiments.
- Diversion rate
  - Since it is difficult and expensive to design, conduct, and control an observation/empirical study in the real world, a variety of literature utilized techniques such as focus group interviews, telephone surveys, and panel surveys to identify possible benefits associated with advanced traveler information systems (ATIS).
  - In terms of induced behavioral changes, a stated survey usually gives a high diversion rate, from 15-30%, sometime even higher if the information provides detailed responding instructions. However, a revealed survey returns a much lower diversion rate, typically less than 15%. Additionally, a few analyses using empirical data also suggests that in real life diversion rate in response to traveler information can be much lower. For instance, some field tests reported diversion rate of only 3% (20, 27-28).

- By analyzing our survey results, the maximum diversion rates by different ITS field elements are approximately 24% for CMS, 6% for HAR, and 13% for 511. These numbers will be further scrutinizedin the later simulation experiments to evaluate the effectiveness of different ITS field elements.

8 COMMUTER TRAVEL SURVEY ANALYSIS

A commuter travel survey was developed, distributed, and analyzed to help explore the effectiveness of information and control ITS field elements on commuter trips. As proposed in the initial overall research methodology, there were two primary goals of the survey. The first goal was to obtain insights about how information and control ITS field elements were perceived by commuters. Commuter perceptions reflect the intangible benefits of selected ITS field elements. The second goal was to gain behavioral inputs to the commuter route-choice model. By combining the commuter route-choice model with the simulation tool, we hope to identify tangible benefits of selected ITS field elements. In particular, the survey examined general perception/usage of selected ITS field elements, and the percentage of commuters who have changed or are willing to change their route choices due to those ITS field elements; the survey controlled for respondents' commuting attributes and demographic characteristics. Note that, as stated in earlier sections, selected ITS field elements examined in the survey include Changeable Message Signs (CMS), Highway Advisory Radio (HAR), 511 phone service, and ramp metering. The survey results can help Caltrans practitioners to better understand the impacts of different information and control ITS field elements and provide practical insights on the operation of current and planned ITS field elements statewide.

8.1 SURVEY METHODOLOGY

8.1.1 SURVEY DESIGN

A 27-question survey questionnaire was developed that covers respondent demographics and a mix of general and specific questions, as well as multiple-choice and open-ended questions.

Questions had been initially broken into four parts based on the different objectives of the survey. First, in order to understand respondents' commuting attributes, questions such as commute frequency, commute origin/destination, commute routes, commute distance/time were asked. Then, the second and third parts of the questionnaire explored general perceptions about selected ITS field elements, the number of people that actually changed route choices, people's willingness to change route choices in the future, people's sensitivity to travel delay when making route choices, etc. Finally, socioeconomic related questions were listed in the last part to control possible demographic factors that might affect travelers' route choices.

The survey questionnaire had been gradually modified and updated according to suggestions and requests from the survey distribution channel – SANDAG 511 (see more information in the following survey distribution section). In particular, additional questions about other commuter travel choices around the San Diego region were added in the final version of survey questionnaire, as the forth part.

The flow chart of the commuter travel survey questionnaire design is shown in Figure 8-1. The survey was posted online on the SANDAG 511 website (http://www.511sd.com/) and distributed around the San Diego region. A printout of the questionnaire is presented in the Appendix II[1].

[1] The format and question numbers of the online survey is slightly different to the paper printout due to the predefined features of the online survey tool selected (i.e., Survey Monkey – www.surveymonkey.com).

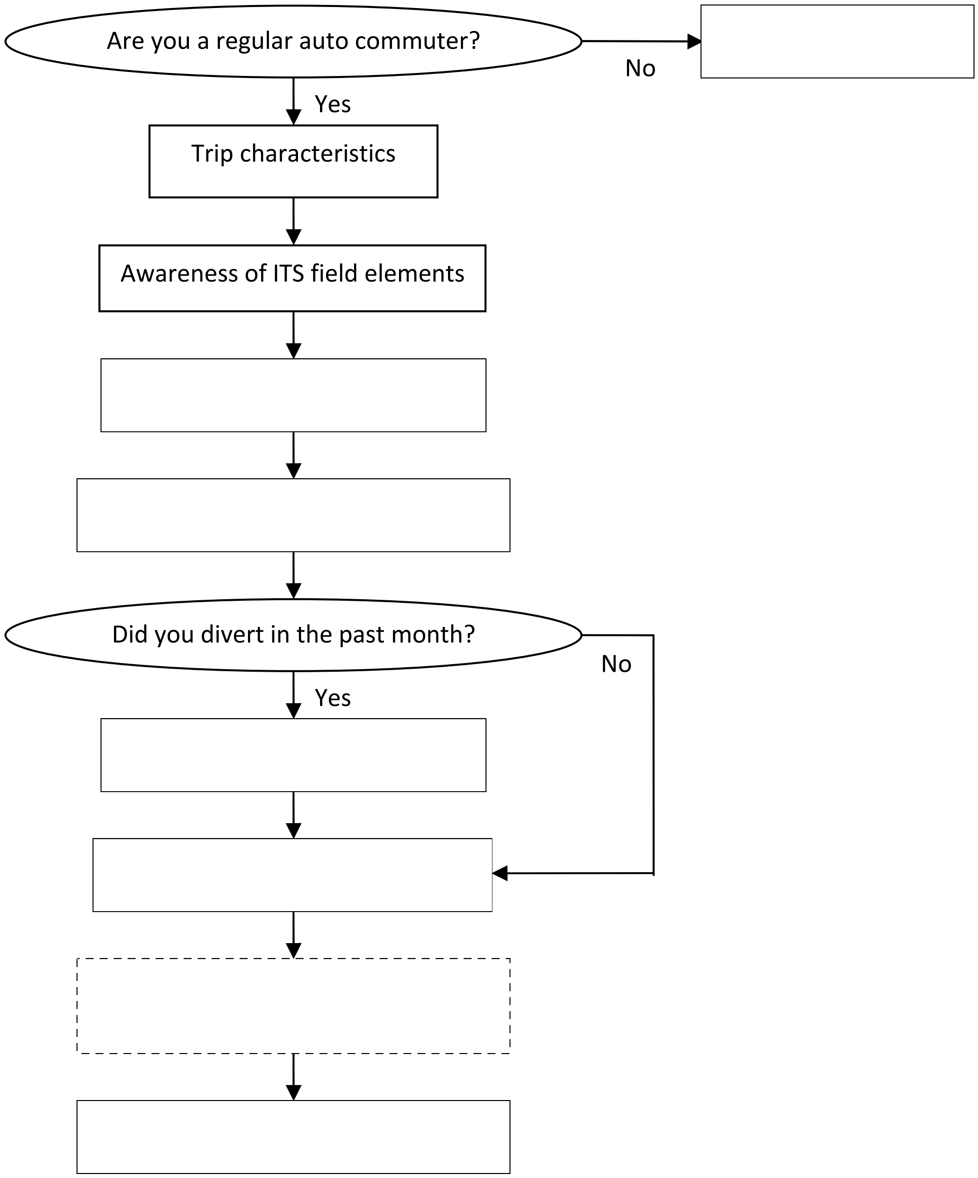


Figure 8-1: Flow Chart of Commuter Travel Survey Questionnaire Design

8.1.2 SURVEY DISTRIBUTION

Many possible distribution channel(s) of the survey were considered. Ideally, we hoped to randomly select traveling commuters in the affected area with all selected information and control ITS field elements, regardless if they have seen/used the elements in their travel before. We also wanted to reach as many survey respondents as possible to gain more samples to truly represent the population and to generate a statistically significant route-choice model. Due to budget and institutional constraints, a number of non-feasible and non-practicable approaches (e.g., onsite direct paper survey questionnaire distribution) were eliminated. Instead, regional 511 websites in California were contacted for the advertisement of the online survey. Time to conduct the survey was initially set to approximately September, 2008, according to the overall schedule of the research project.

Eventually, the online survey was advertised on the SANDAG 511 homepage, which is hosted by the San Diego Association of Governments (SANDAG) and the San Diego Area Transportation Partners, to encourage website visitors to take the survey. With advice from the SANDAG, the survey questionnaire was revised to reflect the traffic context around the San Diego region. The online survey was operational for approximately one month, from mid September to mid October of 2008. The targeted population for the online survey was commuters around the San Diego region.

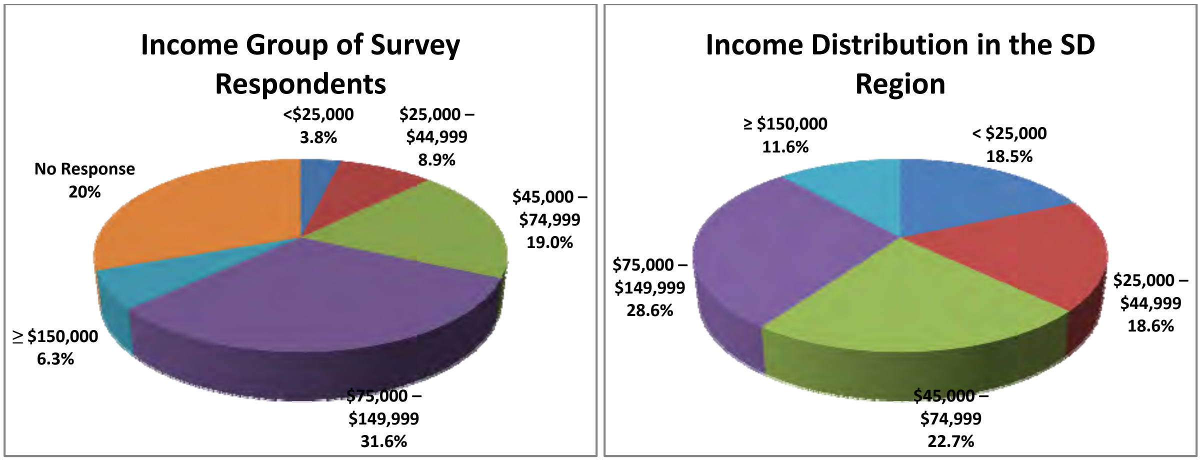
8.2 SURVEY RESPONSE

Over the one-month period from mid September to mid October of 2008, a total of 79 online surveys were collected, including a few incomplete survey responses. All survey data were kept for the data analysis, because all responses contain useful information to the study. A sample size of 79 produces a margin of error of roughly 11% at the 95% confidence level. This means that the 95% confidence interval of a 50/50 split response to a yes/no question is ±11%. The online survey responding population meets the criteria of the study, as 94.3% of survey respondents reported that they had seen/heard of one or more selected ITS field elements. About three quarters of online respondents (74.4%) reported they typically commute 5 times or more per week. The highest concentration of survey responses' commute origins and destinations is listed in Table 8-1, which includes over 50% of total survey respondents.

Table 8-1:Top commute origins and destinations

Rank	Origin		Destination	
	City	Frequency (%)	City	Frequency (%)
1	Escondido	12.82%	San Diego	28.2%
2	San Diego	12.82%	Sorrento Valley	10.3%
3	Rancho Bernardo	7.69%	Downtown San Diego	6.4%
4	El Cajon	6.41%	Del Mar	3.8%
5	Oceanside	5.13%	Rancho Bernardo	3.8%
6	Rancho Penasquitos	5.13%	San Marcos	3.8%

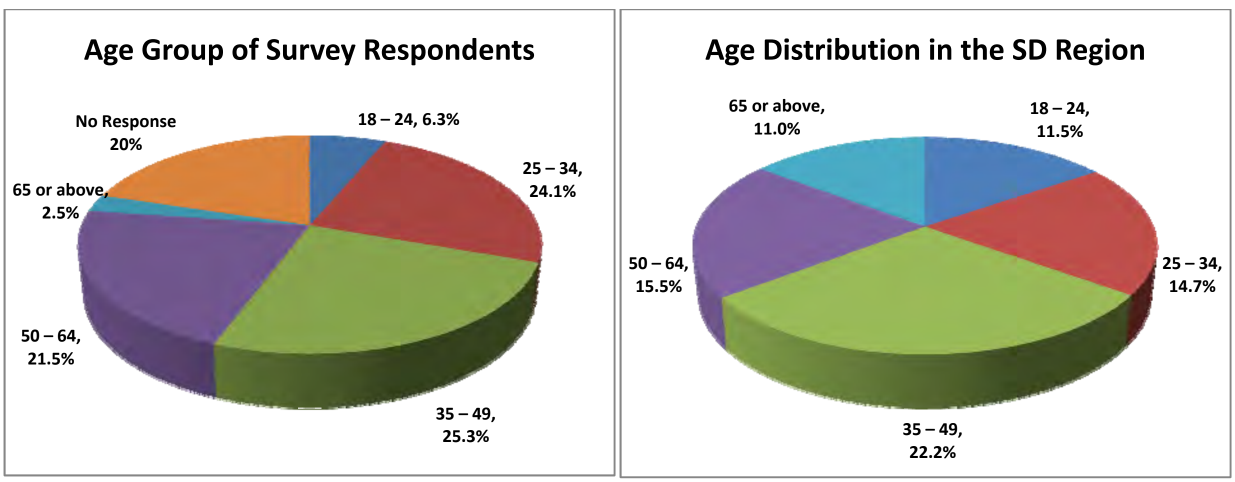
Income results in the CMS survey roughly correspond to the census survey for the San Diego region (San Diego-Carlsbad-San Marcos); however, the survey respondents are slightly skewed towards wealthier households. A possible explanation for this disparity is that auto commuters tend to be higher income earners. There was also a large non-response rate of 20% on the income question, which may hide further upwards bias.



Source: U.S. Census Bureau, 2005-2007 American Community Survey

Figure 8-2: Income comparison between sample and population

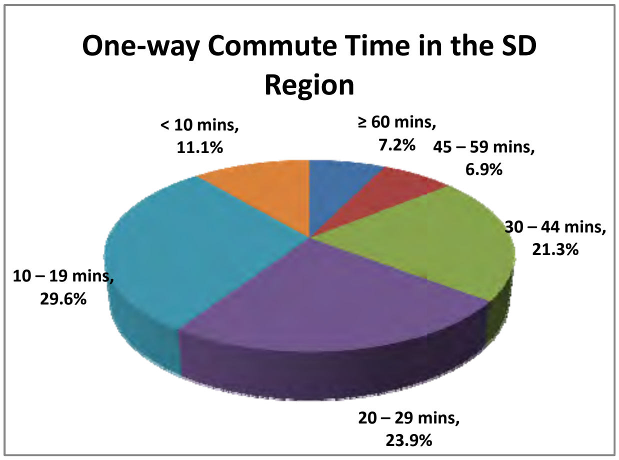
Most respondents were between the ages of 25 and 64 (70.9%). People under the age of 18 were not included in the survey data collection and analysis. Compared to the age distribution in the San Diego region (San Diego-Carlsbad-San Marcos), middle-aged respondents are overrepresented in the survey sample; however, this is the most common age range for commuters, the target population.



Source: U.S. Census Bureau, 2005-2007 American Community Survey

Figure 8-3: Age comparison between sample and population

Average one-way commute time of survey respondents was also compared to the commute time distribution in the San Diego region (San Diego-Carlsbad-San Marcos). Our survey results roughly corresponded to the regional census survey, especially for the group of commuters with 20-45 minute one-way commute time. But more respondents with longer one-way commute time (e.g., 45 minutes or more) were found in our survey, as compared to the commute time distribution. A possible explanation for this disparity is that commuters with longer commute times tend to actively seek and use traffic information disseminated through different channels, so they were more likely to respond to our commuter travel survey.



Source: U.S. Census Bureau, 2005-2007 American Community Survey

Figure 8-4: Age comparison between sample and population

8.3 SURVEY RESULTS

8.3.1 DEMOGRAPHICS AND COMMUTING ATTRIBUTES

More males than females participated in the survey, resulting in a sample population of 49.4% males and 29.1% females with 21.5% not reporting gender. Respondents who responded to other demographic questions are mainly between the ages of 25 and 49 (61.9%), as well as in the age range between 50 and 64 (27.0%); they have a relatively high average household income compared to the regional average, with 54.5% reporting their household income to be $75,000 or above; most of them have completed college, graduate school, or higher (77.6%).

The majority of survey respondents commute 5 times or more per week (74.4%). More than half of respondents start their commute from Escondido, San Diego, Rancho Bernardo, El Cajon, Oceanside, and Rancho Penasquitos, and end their commute at San Diego, Sorrento Valley, Downtown San Diego, Del Mar, Rancho Bernardo, and San Marcos. Most respondents have experienced their commute origins and destinations for more than 3 years (59.5%).

There are several highways that are frequently used as commute routes, such as I-15, I-8, I-5, SR-163, SR-78, SR-56, I-805, SR-52, SR-94. It is found that fewer survey respondents (15.5%) experience relatively longer (≥45miles) one-way commute distance, while there are 37.5% of respondents spend 45 minutes or more for their one-way commute. Similarly, there are 26.8% of respondents have a one-way commute distance less than 15 miles, but only 11.1% of respondents have a one-way commute time that is less than 20 minutes. These results, to some extent, indicate commuters in the San Diego region were typically experiencing a substantial level of traffic congestion. Additionally, the median acceptable amount of time that survey respondents can be late to work/school is approximately 9 minutes, which means commuters typically do not have much flexibility in their commuting schedules. When adjusting for possible en-route traffic congestion, travelers might need to budget a significant amount of extra time for their commute. From this standpoint, information and control ITS field elements can bring notable benefits to commuter trips.

Please see Appendix III (section 1 and 2) for more survey results on the demographic information and commuting attributes of survey respondents.

8.3.2 ABOUT EN-ROUTE INFORMATION AND CONTROL ELEMENTS

The majority of survey respondents (94.3%) had seen and/or heard of selected en-route information and control elements, i.e., CMS,HAR, 511 phone service, and ramp metering. Among these four elements, CMS and ramp metering had the most exposure, with 88.6% and 80% of respondents having seen/heard of them respectively. En-route 511 phone calls received moderate attention (47.1%), followed by HAR (20%). Note: Awareness of 511 phone calls might be over-presented, since the survey was posted on a 511 website.

Although there are moderate to high exposures of selected elements, fewer survey respondents frequently use them in their daily commute, except for ramp metering. For example, 76.1% of survey respondents have never used HAR, and 69.4% of them have never used (en-route) 511 phone service.

In general, CMS and ramp metering are perceived as more useful by survey respondents than 511 phone service and HAR. Respectively, 62.3% and 45.6% of respondents answered “good” or “excellent” for CMS and ramp metering when rating the usefulness; however, only 25.5% and 13.7% of them did so for 511 phone service and HAR. More than half of survey respondents (55.9%) agree or strongly agree that traffic information generally helps them to reduce travel stress. In addition, for CMS, a great number of survey respondents (65.2%) prefer to display travel time all the time, rather than blanking the signs in normal traffic conditions.

Please see Appendix III (section 3) for more survey results on responses about selected information and control elements.

8.3.3 ABOUT EN-ROUTE TRAFFIC DELAY AND ROUTE CHOICE

Many of survey respondents (68.7%) had experienced traffic delays longer than 10 minutes in the months preceding the survey; 66.7% of those delays lasted more than 20 minutes. Interestingly, a majority of commuters (79.5%) received the traffic delay information by self observation of heavy congestion or other sources (e.g., commercial radios), not from information and control ITS field elements. The results also indicate that commuters are unlikely to take an alternate route, since 68.2% respondents reported that they stayed at their usual commute route after getting the traffic delay information.

When asking about general experience, more survey respondents (60%) have changed their typical commute route because of en-route traffic information. Regarding information resources, more survey respondents (55.3%) see CMS as one of their regular en-route traffic information resources. Consistent with findings in the above section, only 13.2% and 15.8% of respondents stated HAR and 511 phone service as their major en-route traffic information resources. Notably, a significant number of respondents indicated their interest in traffic information broadcasted by commercial radio or disseminated via the Internet, although technically the latter is not en-route traffic information. The results emphasize the urgency of deploying and promoting pre-route and en-route ITS elements to extend the coverage of traveler information systems.

Using stated preference questions (See section 13.3.3.1),we found that more commuters are willing to take an alternate route in a future situation of significant traffic delay, while only 10.8% of survey respondents insisted that they won’t detour even with significant traffic delay. Of those who are willing to detour, most are very sensitive to traffic delays. For example, 87% respondents reported that they would detour if the delay is longer than 5 minutes.

This fact shows that commuters will be very responsive to ITS elements if provided with more tangible benefits, i.e., travel time or financial savings.

Please see Appendix III (section 4) for more survey results about en-route traffic delay and route choice.

8.3.4 OTHER COMMUTER TRAVEL CHOICES

As suggested by SANDAG 511, questions about other commuter travel choices around the San Diego region are asked in part 4 of the survey questionnaire. Results show that:

- In response to traffic delays received, a great number of commuters (64.3%) have chosen to leave earlier than originally planned; there are also many commuters have chosen to leave later than originally planned (33.9%), change commute route (37.5%), pay a toll for using express lanes (19.6%), and telecommute (19.6%) etc. Interestingly, relatively few survey respondents stated that they would participate in carpool/vanpool program (12.5%) or use public transportation (8.9%).
- A majority of survey respondents (71.4%) have heard of Ridelink carpool or vanpool program; however, of those who have known about it, only 15.6% of them have used it before.
- A significant number of survey respondents are not against the program or idea of the carpool (66.1%), vanpool (68.9%), or paying a toll for Express Lanes (72.1%), but many of them responded “Neutral” to the statement “for my commute, I like to participate in carpool, vanpool, or pay a toll for Express Lanes.”
- In general, fewer commuters (37.1%) have changed their commute behavior because of the existing ramp metering. Within the group that changed their commute behavior, 56.5% used a different ramp to access the freeway and 43.5% changed their departure time.

Please see Appendix III (section 5) for more survey results about en-route traffic delay and route choice.

8.3.5 WRITE-IN COMMENTS

The final write-in question called for general comments and suggestions. Some respondents offered praise for traffic information disseminated by CMS or the Caltrans website, carpool and vanpool programs, as well as Express Lanes. However, areas for improvement were also identified by many survey respondents. For example, personalized traffic information via email or SMS alert was of interest to some survey respondents, who felt the information would help them plan their trip or efficiently respond to traffic congestion. More reliable, frequent, expanded, and express public transportation services were suggested as means of improving commuting experience. Some commuters commented the potential safety issues associated with unpublicized freeway construction. Additionally, respondents also requested improvement of existing ramp metering, such as dynamic signaling based on real time traffic.

Please see Appendix III (section 6) for detailed write-in comments.

8.4 SURVEY LIMITATIONS

The initial work plan proposed two objectives for the survey. One has been achieved by the survey results (above), which summarize commuters’ perceptions (i.e., intangible benefits) of selected information and control ITS field elements. Unfortunately, due to the limited sample size that we were able to collect via the SANDAG 511 Web site, the second objective, generating a commuter route-choice model using survey data and statistical tool to help capture tangible benefits, was not achievable. In respond to this significant limitation of survey results, we revised the related part of research methodology and designed new approaches to test and identify possible tangible benefits of selected elements. Please see Chapter 7for more detail.

8.5 SURVEY SUMMARY

In summary, our commuter travel survey reveals that:

- A majority of survey respondents have seen/heard of selected en-route information and control elements. In general, commuters value traffic information available to them. For instance, nearly two-thirds of survey respondents agree or strongly agree that traffic information generally helps them to reduce travel stress.
- Among different elements studied, CMS and ramp metering achieved the most exposure. They are also perceived as more useful elements by survey respondents as compared to 511phone service and HAR.
- However, fewer survey respondents frequently use selected elements in their daily commute except for ramp metering. This is partly due to the fact that a majority of commuters received traffic delay information by self observation of heavy congestion or other sources (e.g., commercial radio stations), but not from selected information and control ITS field elements.
- In general, commuters are unlikely to take an alternate route, and they tend to stay at their usual commute route even after getting traffic delay information. But there are many survey respondents who stated that they are willing to take alternate route in the situation of significant traffic delay.
- Commuters will be more affected if provided with more tangible benefits, i.e., travel time or financial savings.

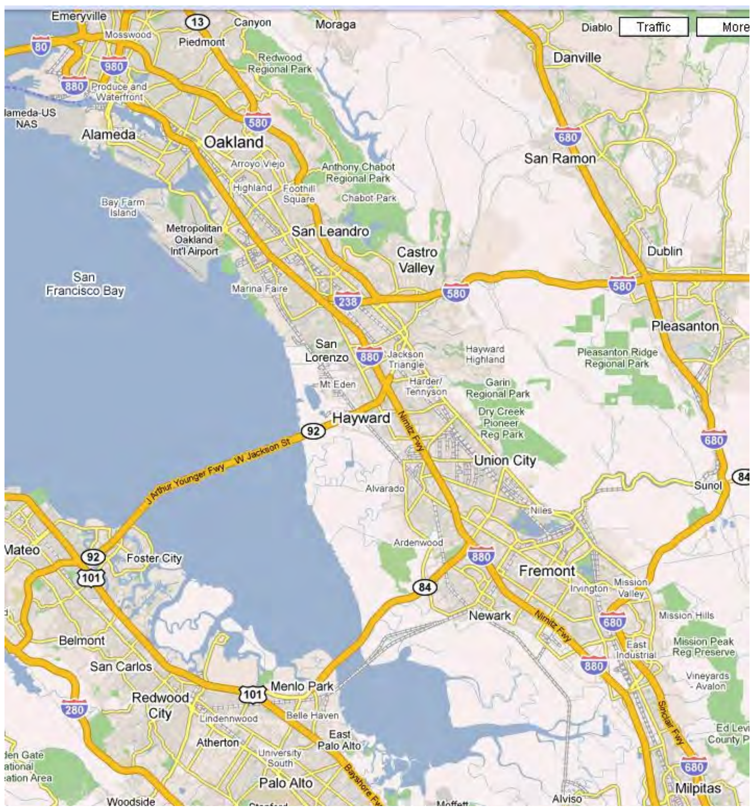
9 COMMUTER TRAVEL SIMULATION ANALYSIS

The microscopic simulation modeling method was used for the evaluation of the effectiveness of traffic information related field elements. Details of the simulation study are explained in this section.

9.1 STUDY SITE

9.1.1 PROJECT SITE

The I-880 corridor is a major north-south freeway located east of the bay in the San Francisco Bay Area in Northern California. There are several major interchanges along I-880. They are I-80, I-980, SR-238, SR-92, SR-84, and SR-237. It is a heavily congested and incident-prone urban corridor. We selected it for the evaluation of the effectiveness of field elements (Figure 9-1).



Source: Google Map

Figure 9-1: I-880 corridor in the San Francisco Bay Area

9.1.2 TRAFFIC CONDITION

I-880 experiences heavy congestion during AM and PM peak periods for both northbound and southbound directions. The speed contour maps are used to describe how congested the corridor is[2]. In these contour maps, x axis shows the time of day and the y axis shows the post mile. For NB, the traffic direction is from low post mile to high post mile. For SB, the traffic direction is from high post mile to low post mile.

For the NB in the morning peak period, as shown in Figure 9-2, there are three major congestion areas. From south to north, they are located from Whipple Rd to Tennyson Rd, between Washington Blvd / SR-238 and 98th Ave, and between 23rd St and 66th Ave. For the SB in the morning peak period, as shown in Figure 9-3, there are two major congestion areas. From south to north, they are located between Tennyson Rd and Whipple Rd, and between 23rd St and Washington Blvd / SR-238.

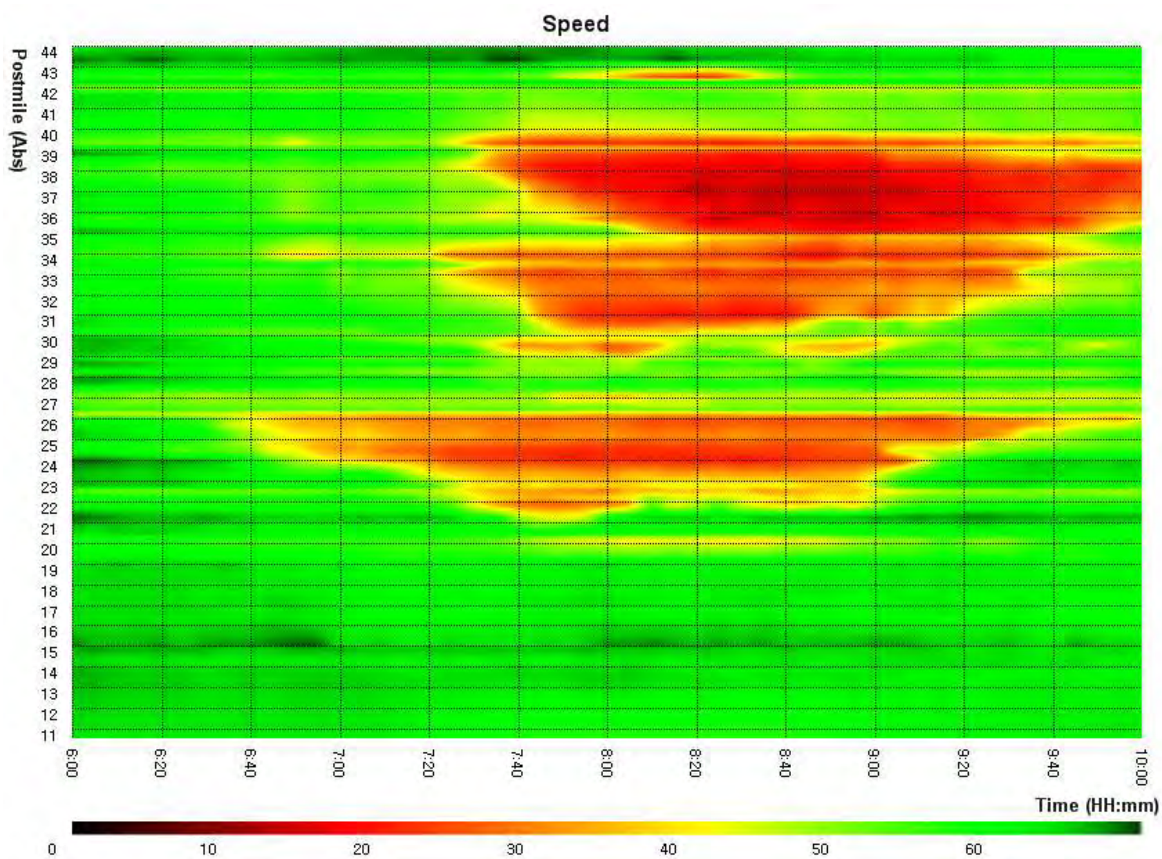


Figure 9-2: Northbound morning traffic speed contour

[2] Ban, J. X., Chu, L., and Benouar, H. (2008) Bottleneck Identification and Calibration for Corridor Management Planning, Transportation Research Record 1999, pp 40-53.

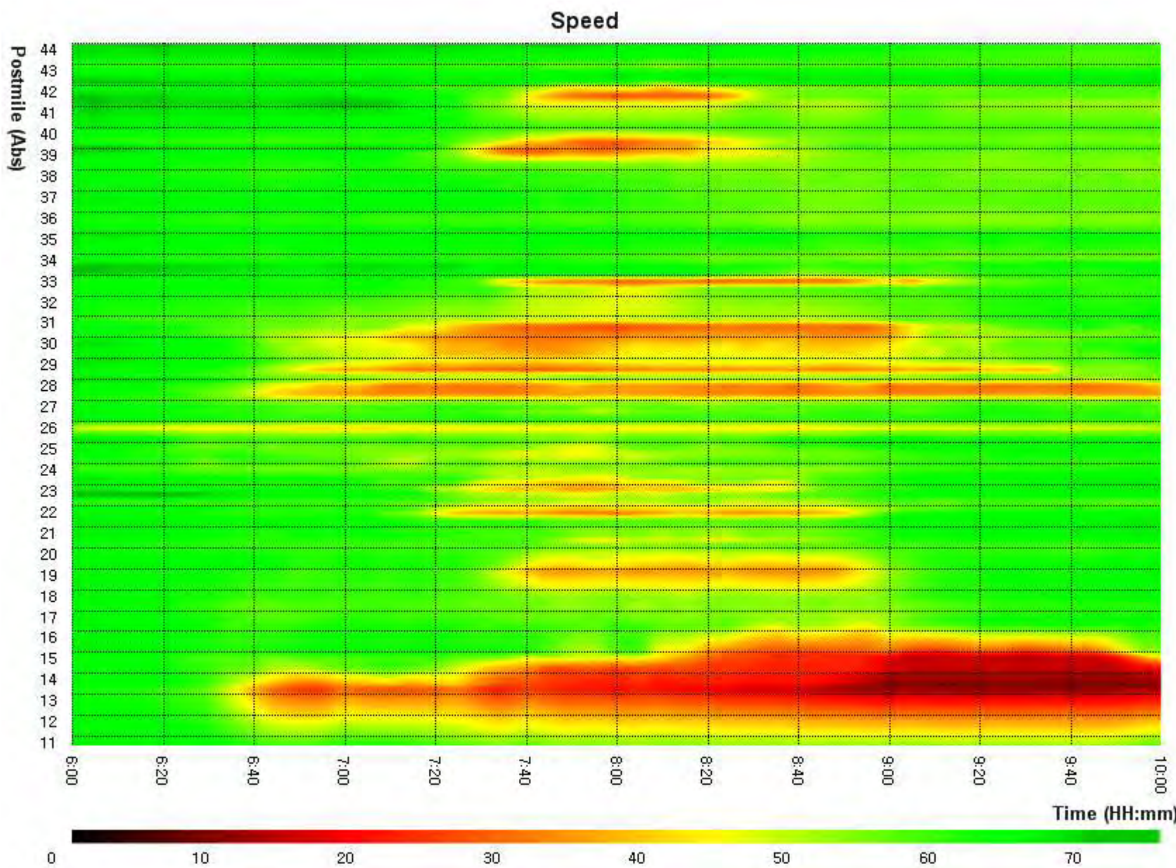


Figure 9-3: Southbound morning traffic speed contour

Accordingly, high delays have been measured for the I-880 corridor. Table 9-1 lists the delay information, in vehicle-hours, based on the time-of-day for both directions from 2003 to 2005.

Table 9-1:Delay of I-880 Corridor

	Northbound Direction				
Year	AM Peak	Mid Day	Evening and Early AM	PM Peak	Total Daily
2003	1,499	1,237	552	2,547	5,835
2004	1,124	1,067	360	2,317	4,867
2005	1,331	1,434	285	2,351	5,402
	Southbound Direction				
Year	AM Peak	Mid Day	Evening and Early AM	PM Peak	Total Daily
2003	1,924	1,397	276	2,249	5,846
2004	1,728	1,796	291	2,677	6,491
2005	1,678	2,196	232	2,885	6,991

I-880 suffers from many traffic incidents and accidents. Traffic incidents can be defined as "an unplanned randomly occurring traffic event that adversely effects normal traffic operations."[3] This definition of incidents is very broad and may contain accidents (car crashes), debris on the roadway, stalled vehicles, etc. Figure 9-4 plots the incidents that occurred along NB I-880 for March 1 – 10 of 2005. The mean plot is the number of incidents averaged over the 10 days for every half an hour period of day; while the maximum and minimum plots correspond to the largest number and smallest number of incidents in the 10 days for every half an hour period.

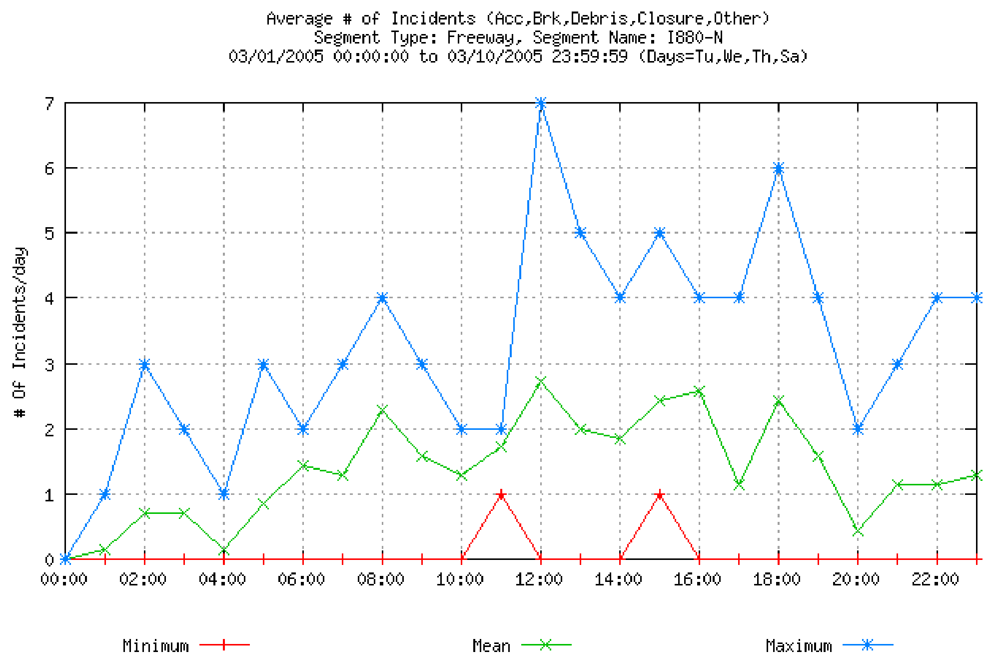


Figure 9-4: Incidents on NB I-880 for March of 2005

Accidents are specifically defined as vehicle crashes on the roadway. Therefore, accidents can be treated as one type of traffic incident. Figure 9-5depicts the average daily number of accidents that occurred for both directions of I-880. The data was obtained from the TASAS database and averaged for each month from 1999 to the end of 2004. There are at least 8 collisions daily for the corridor during the above time period.

[3] Traffic Management Data Dictionary (TMDD) and Message Sets for External Traffic Management Center Communications (MS/ETMCC) Web site. Institute of Transportation Engineers. (http://www.ite.org/tmdd)

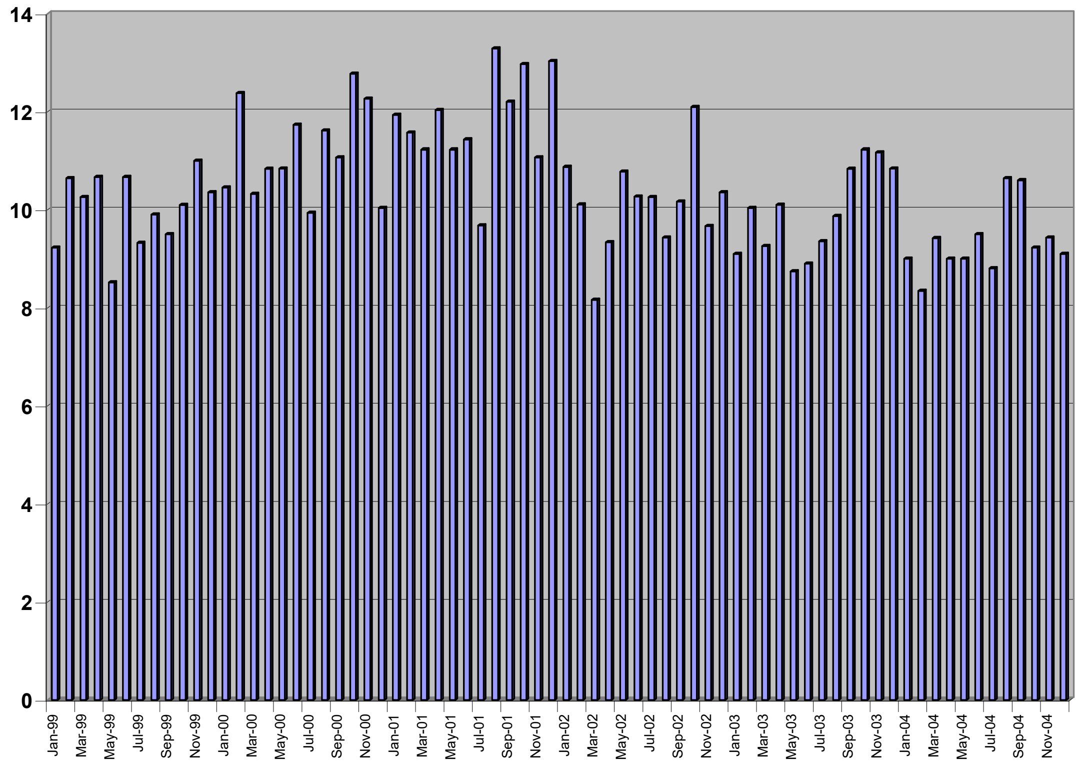


Figure 9-5: Average daily accidents for I-880 (both directions)

9.1.3 CURRENT FIELD ELEMENTS

The field elements along I-880 include loop detectors, ramp meters, CMS, and HARs. Detectors are placed every half to one mile, depending on locations. Ramp meters are placed at every entrance ramp. There are more than ten CMS along I-880 and other connected freeways close to I-880, as shown in Table 9-2. They are potentially used for the traffic management for I-880.

Table 9-2: List of CMS

ID	Route	Direction	Location
CM098	I-880	NB	South of Oak St
CM057	I-880	SB	South of Marina Blvd
CM008	I-880	NB	900ft South of Hacienda Ave
CM010	I-880	NB	1000ft North of Industrial Pkwy
CM030	I-880	SB	North of Alvarado Blvd
CM022	I-880	SB	1 mile North of Dixon Landing Rd
CM077	I-880	NB	North of Dixon Landing Rd
CM074	I-880	SB	North of Broadway Rd
CMS007	SR-238	NB	North of Ashland Ave
CMS009	SR-92	EB	1000ft East of Industrial Blvd
CMS083	SR-92	WB	San Mateo Bridge Plaza

CMS059	SR-84	NB	1700ft East of Thornton Ave
CMS061	SR-84	SB	At KGO Station
CMS068			7TH St or TO S880

9.2 SCENARIO DEVELOPMENT

9.2.1 MICRO-SIMULATION MODEL

The I-880 Paramics model was developed and calibrated in a previous study[4]. This project took the existing model and then tested various scenarios for this study. A snapshot of the I-880 model is shown in Figure 9-6.

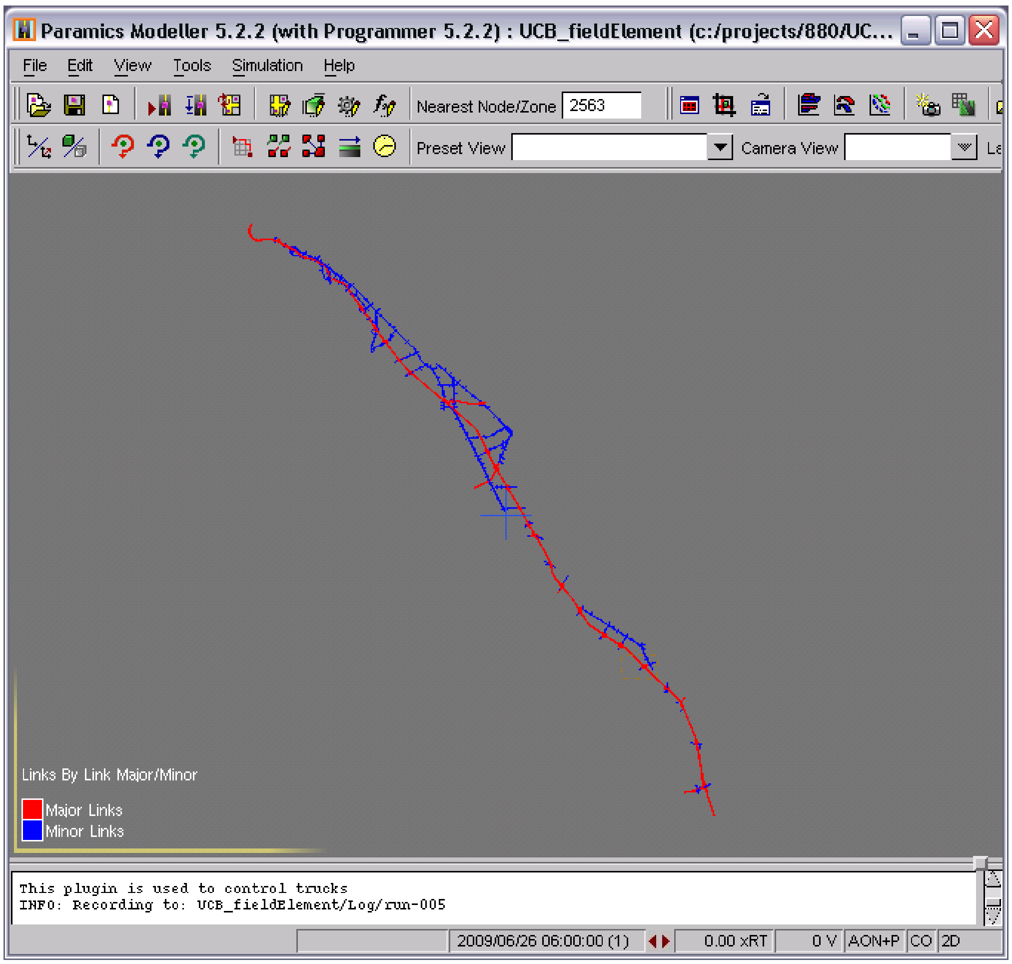


Figure 9-6: I-880 Paramics model

The original I-880 model has a total of four hours, i.e. from 6:00 to 10:00, for the AM period. For this study, our adjusted model only has the first three hours. We set up 6:00 – 7:00 AM as the warm-up period; 7:00 – 8:00 AM as the rush period, and 8:00 – 9:00 AM as the cool-down period, during which there is zero demand.

[4] CCIT (2006) Corridor Management Plan Demonstration – Final Report, CCIT Research Report.

The adjusted model had an incident occur during the rush period at 7:00, lasting for 30 minutes, as a way to test the performance of different scenarios (See Section 9.2.2for further explanation). Due to the incident, many vehicles were queued up in the network and some demands could not be released. This is the reason to have the cool-down period with zero demand. During the cool-down period, all the demands were able to be fully released into the network and all the queues were able to be fully dissipated. As a result, all study scenarios have the same or similar trips and thus can be compared against each other.

The I-880 model has a total of 168 zones. The zones were numbered sequentially from the far south of the network to the far north. Figure 9-7is the demand contour for the rush period (7:00 – 8:00 AM) for all the O-D zones. The map clearly shows there was large demand between only certain O-D zones; while the demand is almost zero for most ODs. Some major zones are identified from the map and their corresponding locations are listed as follows:

- Zone 168: I-880 northern end
- Zone 162: I-980
- Zone 152-159: Oakland downtown zones
- Zone 119: Airport
- Zone 86: SR238 (two directions)
- Zone 51: SR-92 western end
- Zone 68: SR-92 eastern end
- Zone 67: Mission Blvd southern end
- Zone 2: 237 Western
- Zone 4: 237 eastern end
- Zone 1: I-880 southern

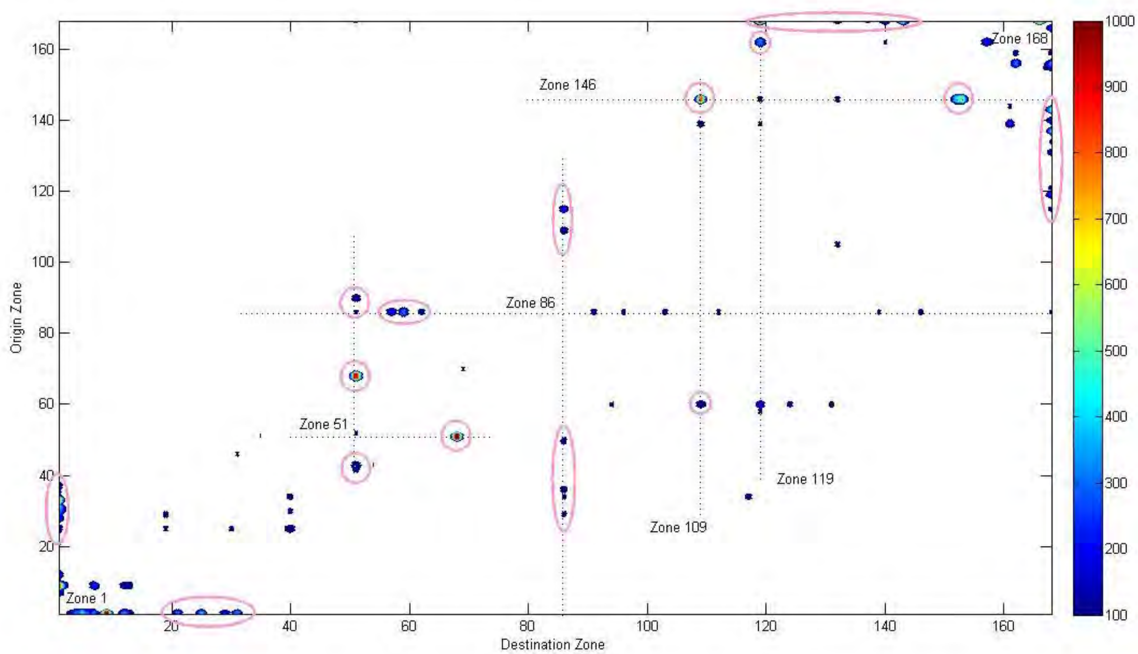


Figure 9-7: Demand contour map during rush period

Some of these zones serve only as origins or destinations; while others serve as both. Also a visual check reveals that the demand dots generally lay on the diagonal of the map, which means most of the traffic was between zones that are not too far away. O-D pairs that have relatively large demand and have available diversion routes between them were pin-pointed with pink ellipses. These pairs serve as candidates for vehicle diversion.

9.2.2 INCIDENT AND DIVERSION

It usually takes some time for traffic agencies to detect, verify, and respond to an incident with a traffic management plan. The incident detection and response time varies; it usually takes about 20-30 minutes, according to our literature review. We use 20 minutes in this study[5].

For this study, the incident we modeled is located between 92 (W Jackson St) and W Tennyson Rd along SB I- 880. The leftmost two lanes are closed for 30 minutes due to the incident.

Traffic agencies usually utilize their field elements, such as CMS, HAR, 511, radio stations etc., to convey incident information. The provided information may thus cause vehicle diversion. The diversion can be further divided into two categories: CMS diversion and self-diversion.

9.2.3 CMS DIVERSION

Traffic agencies like Caltrans usually convey traffic incident information through CMS, which are very visible for travelers en-route.

If the diversion information on CMS is strong, vehicles may divert to the alternative routes. The alternative route may be provided by CMS and controlled by traffic agencies. The distinguishing feature of this type of diversion is that vehicles divert at a fixed location and then follow a specified route. When the full route is provided through CMS, we called it a “full alternative route based CMS diversion.”In most cases, there won't be any diversion route information. CMS can only carry messages like “Major Incident at XXXX, Take Alternative Route.” We called this type of CMS diversion “partial alternative route based CMS diversion.” This is because those drivers who are willing to divert will exit at the same off-ramp and then they will need to find an alternative route based on their familiarity of the local streets in relation to their destinations. With the popularity and wide availability of GPS navigation systems, some drivers may easily find alternative routes.

The process of CMS diversion can be described as follows:

- All possible diversion routes are pre-defined by TMC. For each CMS sign, TMC operators usually know which diversion routes are associated with it under different incident conditions.
- Incident occurs.
- Incident gets verified and TMC operators post traffic information to CMS.
- TMC operators provide diversion information.
- Some drivers divert if they are familiar with the local streets or if the full diversion route is provided through signs along the detour route.
- TMC operators may stop displaying diversion information on the CMS.

[5] Chu, L., Liu X., Recker, W. (2004) Using Microscopic Simulation to Evaluate Potential Intelligent Transportation System Strategies under Nonrecurrent Congestion, Transportation Research Record 1886, pp.76-84.

- Traffic congestion gets relieved and then diversion ends.

A Paramics plug-in was developed to implement this type of diversion. The plug-in works with either the full alternate route or partial alternative route (i.e., whether or not a route alternative is provided along with the basic diversion announcement).

In our study, we performed many preliminary simulation runs to find appropriate diversion paths for different OD pairs, as mentioned above. We explored longer diversion paths. However, longer routes are inferior because, compared with freeways, local routes usually have more signals and much lower speed limits. Therefore, the longer the diversion path, the more likely it is inferior compared with the original path. Also drivers are likely to prefer shorter diversion paths as people always want to return to freeway as soon as possible.

The final diversion includes partial alternative route based CMS diversion and full alternative route based CMS diversion.

9.2.4 SELF-DIVERSION BASED ON 511 TYPE TRAFFIC INFORMATION

Another type of diversion is caused by traffic information media such as HAR, radio, and 511. This type of traffic information may cause vehicle diversion anywhere in the network. Only informed travelers who are familiar with the alternative routes are able to divert. We call this group of drivers Qualified Informed Drivers (QID).

QID are travelers who may divert. They may evaluate the current situation based on their experiences and then decide whether to maintain their original route or taking an alternative route. For those travelers who obtain traffic information from various sources but don't have any plan to divert, the traffic information is only used for relieving their anxiety. They won't be counted as QID.

A typical process of this type of diversion is as follows:

- Incident occurs.
- Incident gets verified and serious impact is expected or congestion occurs.
- Pre-trip travelers check 511 and decide to take an alternative route due to the occurrence of the incident.
- Drivers check 511 during the trip when they face abnormal congestion. After getting incident and diversion information, they divert to an alternative route.

A reasonable QID can be determined based on a survey with questions like the following:

- What is the percentage of drivers who check 511 or other media before the trip? What is their response if there is an incident on their route?
- What is the percentage of drivers who check 511 when hitting abnormal congestion or other media during the trip? What is their response if there is an incident on its way?
- What is the percentage of GPS units that have real-time traffic and re-routing functionality?

According to literature reviews[6], 20% of QID makes the network reach its best system performance, i.e., equilibrium. As a result, we use 20% QID for some cases of this study to show the potential best performance of self-diversion.

The way to model QID and their route choice behaviors in Paramics is to use dynamic feedback assignment. There is a parameter called familiarity, corresponding to the percentage of a driver group or vehicle type to be QID.

9.2.5 SCENARIO DESIGN

Five groups of scenarios were set up for the testing of the effectiveness of vehicle diversion. The first two scenarios are basic scenarios. The other three scenario groups implement different diversion rates and QID levels and a combination of a certain diversion rate and QID level. When performing the evaluation, Scenarios 3 to 5 were compared against the two basic scenarios.

- Scenario 1: No-incident.
- Scenario 2: Incident only (without any diversion).
- Scenario 3: Incident + CMS diversion. Different diversion rates were tested for sensitivity analysis and to find out the best diversion rate. Diversion rate corresponds to the percentage of all the vehicles that take a certain diversion path when they pass a decision link that is associated with a CMS sign. In our study, we conduct simulations with diversion rates of 10%, 20%, 30% and 40%.
- Scenario 4: Incident + self diversion. The diversion paths for these drivers are not given by the TMC, but are decided based on drivers' experience and familiarity on this stretch of routes.
- Scenario 5: Incident + CMS diversion + self diversion. After we decide on the best CMS diversion rate, we combine CMS diversion with different self diversion rates (different familiarity levels) to look for the best TMC scheme for the network. We tried different QID levels ranging from 5% to 25% in our study.

9.3 EVALUATION

9.3.1 MEASURE OF EFFECTIVENESS

The measure of effectiveness (MOEs) for this study includes:

- Overall system performance, including average travel time, average speed, vehicle miles traveled (VMT), and vehicle hours traveled (VHT);
- Queue lengths and severity of congestion, obtained through speed contour maps drawn based on point detector data collected from simulation;
- Bottleneck throughput, i.e. traffic outflows at the bottleneck location (corresponding to the capacity of the bottlenecks).
- Vehicle emission, focusing on Green House Gas (GHG), i.e. CO_2 emission and fuel consumption.

These MOEs are collected using either the standard Paramics measurement functions or the plug-ins we developed. The emission data are collected using the CMEM plug-in developed by UC Riverside.

[6] Chu, L., Liu X., Recker, W. (2004) Using Microscopic Simulation to Evaluate Potential Intelligent Transportation System Strategies under Nonrecurrent Congestion, Transportation Research Record 1886, pp.76-84.

9.3.2 SIMULATION RESULTS

9.3.2.1 OVERALL SYSTEM PERFORMANCE

Average travel time, average speed, VMT, and VHT were collected directly using Paramics' measurement function. The data for the whole network over the 3 hour simulation period were used for analysis. For the no-incident basic scenario, its overall performance was as follows:

- Average travel time = 965.3 seconds
- Average speed = 31.5 mph
- VMT = 1036323 miles
- VHT = 32883 hours

The results for other scenarios (incident and diversions) are shown in Figure 9-8 through Figure 9-11.

First, we studied the effect of CMS diversions on overall system performance. The diversion rate was set to be 0% (no diversion), 10%, 20% and 40% to analyze its sensitivity. According to Figure 9-8 through Figure 9-11, the general result was that CMS diversion was able to increase the overall system performance. Next, we studied on the optimal CMS diversion rate.

As shown in Figure 9-8 and Figure 9-9, 20% diversion rate seems to be the best solution based on average travel time and average speed. Under this diversion scenario, average travel time was reduced from 1016 seconds to 967.5 seconds (corresponding to 4.7% reduction); average speed was increased from 29.9 mph to 31.4 mph (corresponding to 5.0% increase). Note the average travel time and the average speed are averaged across the whole network for all the vehicles, thus taking into account the diverted traffic on alternative routes.

VMT and VHT are not very intuitive measurements because drivers have different origins and destinations and thus have different trip lengths. A driver taking a longer route to the destination will have a larger VMT, but it does not mean real benefit for this driver. However, within the time and space scope of our network, generally larger VMTs (more drivers finishing their trips) and smaller VHTs (drivers traveling faster) mean better system performance. Based on Figure 9-10 and Figure 9-11, 20% diversion gives the best VMT and 30% diversion gives the best VHT, though 20% diversion gets a very close second place.

Therefore, based on all the four MOEs, we can safely claim that 20% diversion rate gives the best overall improvements to the system. In the next step's study of QID levels, we will set the diversion rate to 20% in order to see if there are any additional benefits to be obtained from self-diversion when CMS diversion has reached its optimal condition.

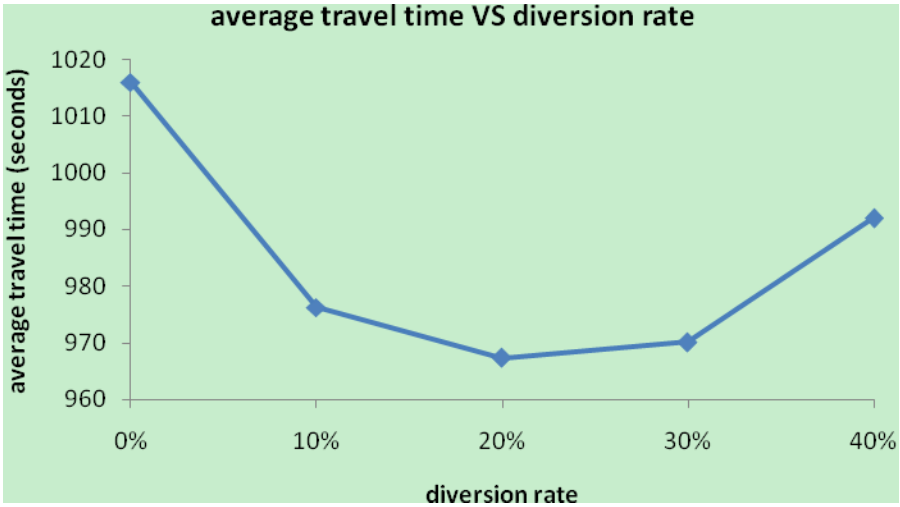


Figure 9-8: Average travel time for different diversion rates

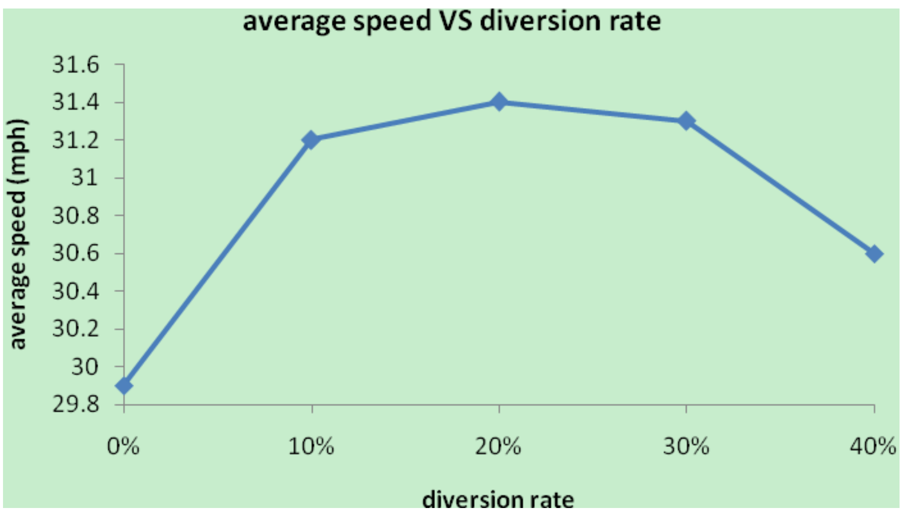


Figure 9-9: Average speed for different diversion rates

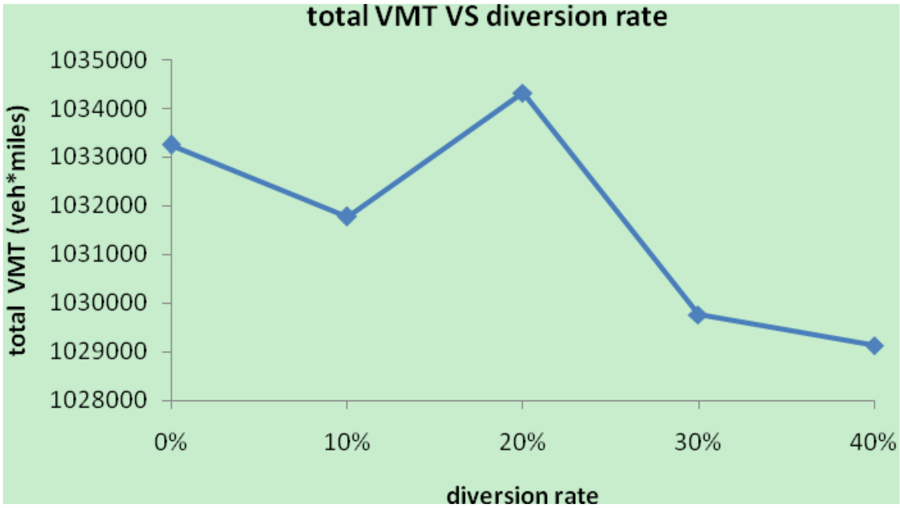


Figure 9-10: Total VMT under different diversion rates

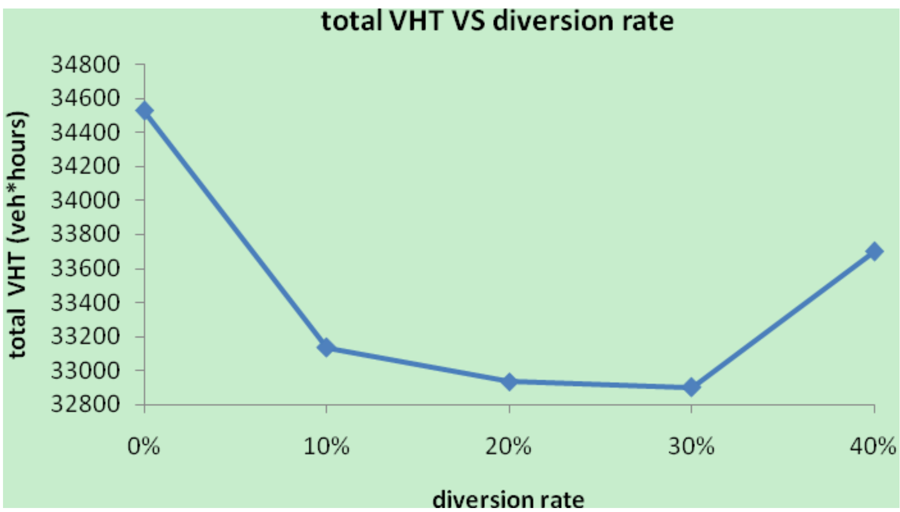


Figure 9-11: Total VHT under different diversion rates

By fixing a 20% CMS diversion rate, we further investigate the effects of different QID levels on overall system performance. The results are shown in Figure 9-12 through Figure 9-15.

In terms of average travel time and average travel speed, the trend is that the higher the QID level, the better the system performance. However, the largest improvement occurs when QID level increases from 15% to 20%, which sees a decrease of travel time by 35.8 seconds and an increase of speed by 1.2 mph. At 20% QID level, average travel time is 90.5 seconds less than the incident scenario, which is a very great improvement of around 9%. Average speed is improved on a similar scale. A further increase of QID level to 25% only shows minor improvement for the system. All the measurements show similar patterns with the exception of VMT, on which 15%

QID level yields the largest value. Therefore, we can safely say a QID level between 15%-20% (closer to 20%) would be best for the system. The findings are in accordance with literature recommendations.

The implication of these findings is that there exists a certain range of QID level that benefits the system greatly. However, further increase on QID level does not provide as great benefit. QID depends on market penetration of the traffic information media. How to make traffic information easily accessible is the key to the increase of QID. Although self diversion benefits both traffic agencies and travelers, it is hard to measure its effectiveness using real-world data. It is strongly recommended that more attention needs to be given to the 511 type traffic information media.

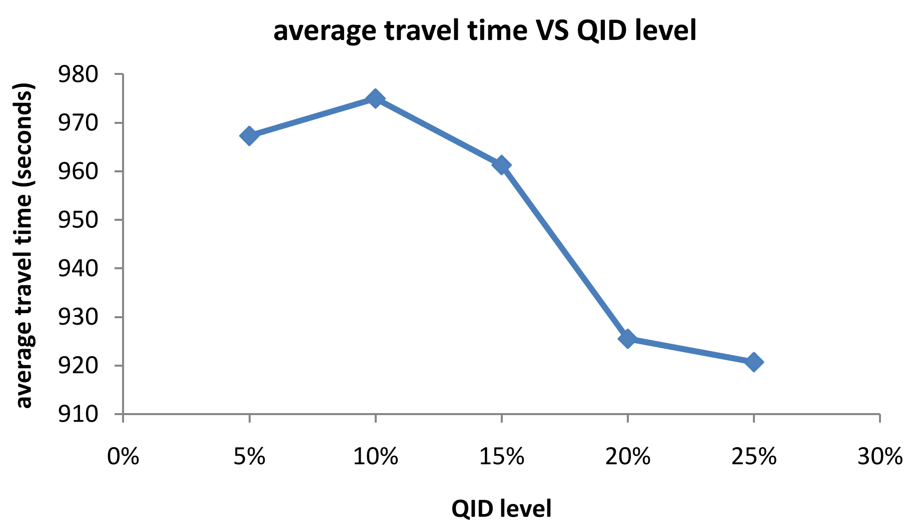


Figure 9-12: Average travel time for different QID levels

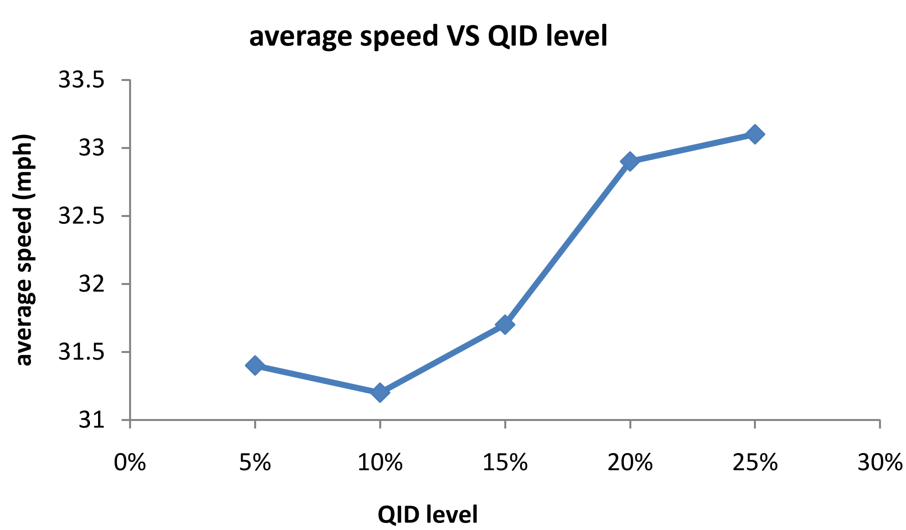


Figure 9-13: Average speed for different QID levels

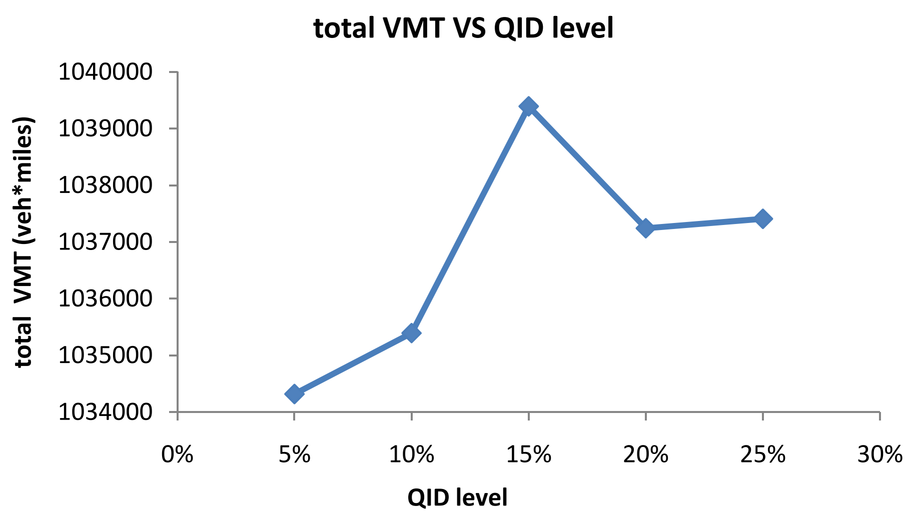


Figure 9-14: Average vehicle-miles-traveled for different QID levels

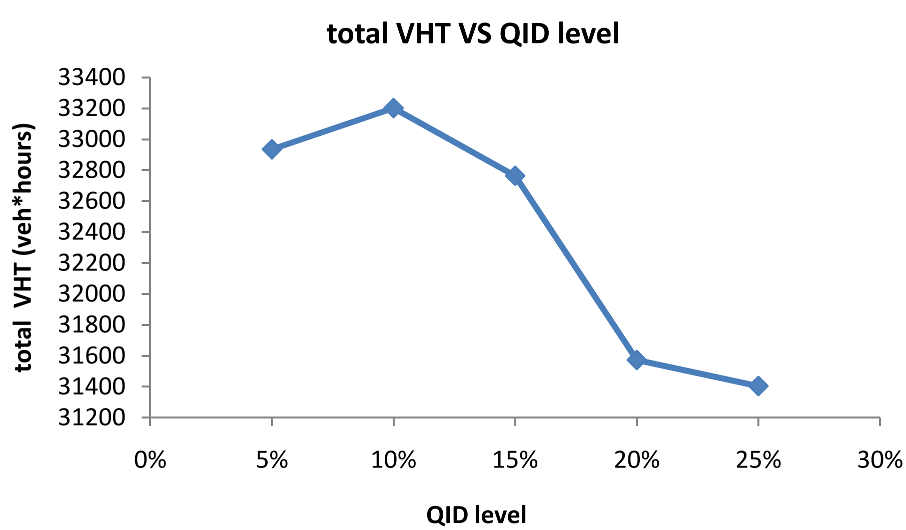


Figure 9-15: Average vehicle-hour-traveled for different QID levels

9.3.2.2 QUEUE LENGTHS AND SEVERITY OF CONGESTION

Speed contour maps were plotted based on 5-minute aggregated detector data along I-880 to quantitatively measure the severity of the congestion and the physical length of the queues. The following maps show the speed contours for different scenarios. The incident location is at around post mile (PM) 16 on the southbound I-880. Note that the 0 speed area on the lower-right corner of every map corresponds to the cool down period after

8:00AM, during which no traffic is released into the network. For the convenience of the analysis, we neglected the time-space area from after PM 29 and after 8:00 AM.

Figure 9-16 shows the speed contour map for southbound I-880 on an incident-free morning (Scenario 1). All the congestion can be regarded as recurrent and formed due to demand exceeding capacity (the so-called bottlenecks). Based on the contour map, there are mainly two bottlenecks on this stretch of freeway. The first one is located near PM 11 (we will call it Bottleneck PM 11), which first activates at around 7:10 and becomes a very severe bottleneck after 7:40, with the queues backing up over 7 miles. Further scrutiny of the network shows this bottleneck may be caused by a combination of the Alvarado on-ramp and a downstream curve section on I-880. The second bottleneck, which is also the main bottleneck, is located near PM 18, downstream of the intersection between I-880 and W A St (we will call it Bottleneck PM 18). This bottleneck activates shortly after 6:40 and lasts until 8:15 (at this location) with the help of the cool-down period. The queues back up almost to the north end of the network. Based on the speed contour map, the effect of the second bottleneck is very widespread, though not as severe as the first one if only in terms of travel speed. There is a third bottleneck located near PM 3. But it is mild in most cases and thus will not be considered in our analysis.

Figure 9-17 shows the speed contour map for southbound I-880 for Scenario 2, in which there is an incident blocking two lanes (the median lane and second-to-median lane) from 7:00 to 7:30AM. The incident is located at around PM 16. It's clear from the map that a new bottleneck (we will call it the new bottleneck) is created by the incident after 7:00AM and lasts until the incident is cleared (7:30AM). Clearly the new bottleneck has a smaller capacity than the recurrent Bottleneck PM 18 and therefore when the new bottleneck hits Bottleneck PM 18, it further decreases the capacity at PM 18. We can qualitatively tell from the map that due to the incident, Bottleneck PM 18 creates more severe congestion (speed drops more) and also lasts longer than before, until around 8:25. Interestingly though not surprisingly, since the new bottleneck actually starves the flow passing through it, we observe a mitigation effect on downstream bottleneck, i.e. Bottleneck PM 11 was not active until 7:40, the queues were 2 miles shorter, and the speeds in the queue were much higher than in Scenario 1. However, we need to keep in mind that this mitigation effect is achieved by a more severe bottleneck upstream; therefore, the downstream mitigation does not mean any improvement on a system-wide level. The data collected from Paramics confirmed the deleterious effect of the incident on the network. The average travel time for all the vehicles in the network is 965 seconds without the incident; with the incident, however, the average travel time increases to 1016 seconds (over 5% increase). The average travel speed also drops from 31.5 mph to 29.9 mph (over 5% decrease). The effects are huge considering there are altogether over 120,000 vehicles released into the network during the 3 hour period. As a matter of fact, the vehicle-hour delay increases by another 1735 veh*hr due to the incident on the system-wide level.

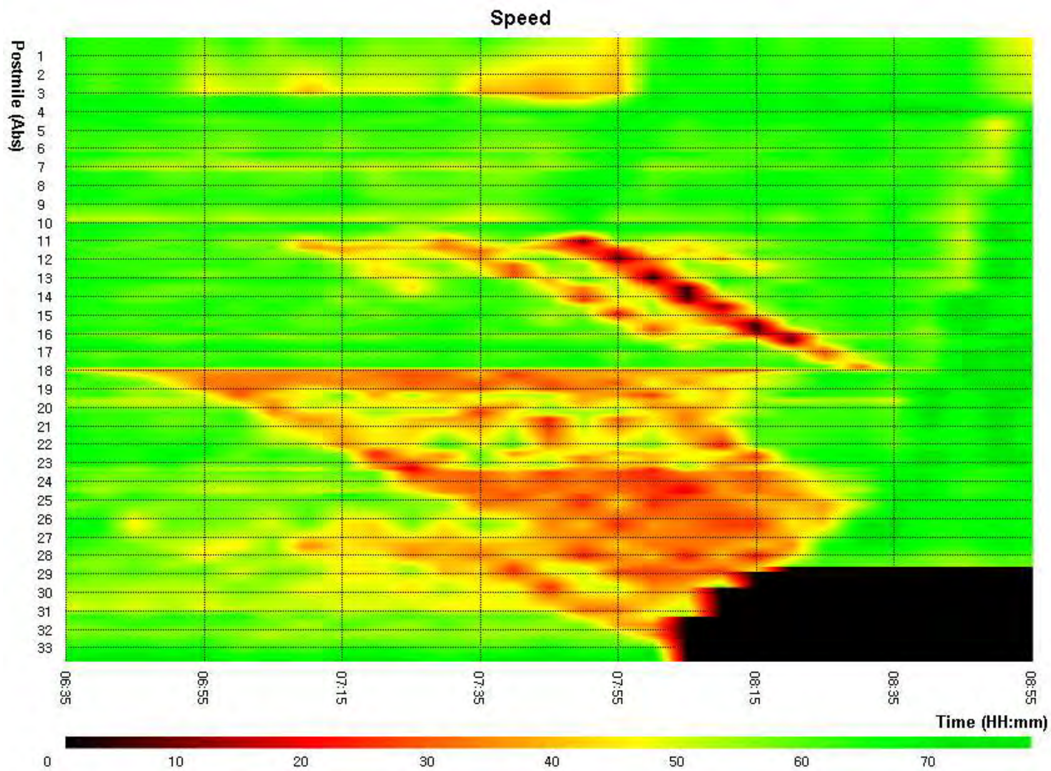


Figure 9-16: Speed contour for I-880, Scenario 1: No incident

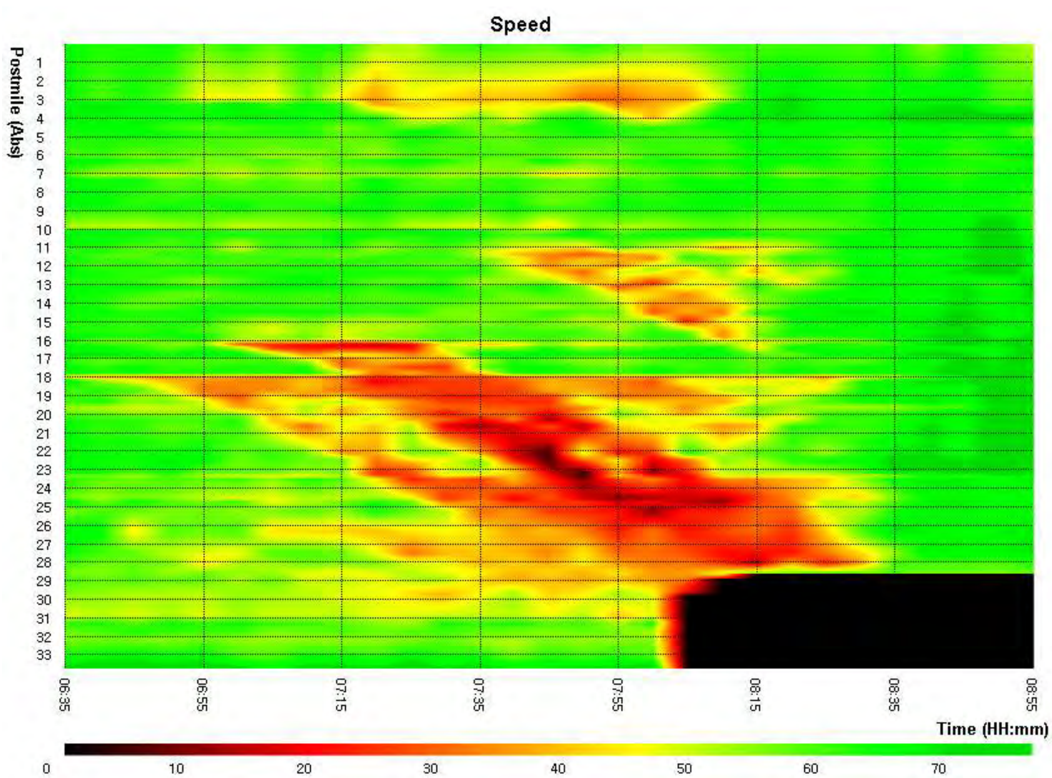


Figure 9-17: Speed contour for I-880, Scenario 2: Two-lane-closure incident

As shown previously, 20% diversion gives the best overall results in terms of average travel time and travel speed. The speed contour map for Scenario 3 (with 20% diversion rate) is shown in Figure 9-18. A rough comparison with Scenario 2 shows that even though the queue length and duration remain at a similar level, the congestion is not as severe, i.e. the speeds in queues are higher than in Scenario 2. Also, the diversion scheme appears to help with the Bottleneck PM 11, too: the maximum queue length due to the bottleneck was further reduced to only about 4 miles, 1 mile shorter than in Scenario 2. The average travel time decreases to 967.3 seconds, just 2.3 seconds more than Scenario 1 (i.e. the no incident case). The diversion scheme showed great improvement on the network after the incident occurred.

Figure 9-19 is the speed contour map for Scenario 4, which implements 20% QID level and no CMS diversion. As is stated before, QID is a parameter corresponding to the percentage of drivers who can get information from traffic information media such as 511 and HAR, thus may make the decision to divert in case of congestion or incident. The diversion paths for these drivers are not given by the TMC, but are decided based on drivers' experience and familiarity on this stretch of routes. The speed map shows that an increase in QID can also help mitigate the congestion. For the first time a reduction in queue length for the main bottleneck (the new bottleneck and Bottleneck PM 18) is achieved. The main queues back up to around PM 27, which is at least 2 miles shorter than in previous scenarios (although some moderate residual queues are observed to have backed up to PM 29 too). Another important feature is that queues are dissipated faster. The maps show that on the section between PM 24 to PM 28, queues are cleared at around 8:15 AM for this scenario while they only fully dissipate at around 8:30 AM in Scenario 2 and Scenario 3.

Considering the wide influence of this congestion, it is no doubt that this improvement will have a positive effect on the network as a whole. Data show that average travel time for all vehicles is 930.4 seconds and the average speed is 32.7 mph for Scenario 4. Compared to Scenario 2, it improves the system greatly, reducing travel time by 85.6 seconds (8.4% decrease) and increasing the average travel speed by 2.8 mph (9.4% increase). This is equivalent to a decrease of approximately 2900 veh*hrs of delay.

Figure 9-20 is the speed contour map for Scenario 5, which has 20% CMS diversion rate together with a 20% QID level self-diversion. Compared with previous scenarios, the queues are even shorter in both time and space, and less severe. The average travel time for all vehicles is 925.5 seconds and the average speed is 32.9 mph. It yields the best results among all five scenarios, demonstrating that if we combine different traffic management control schemes (CMS & 511/HAR), it's possible to have an overall better effect on the network.

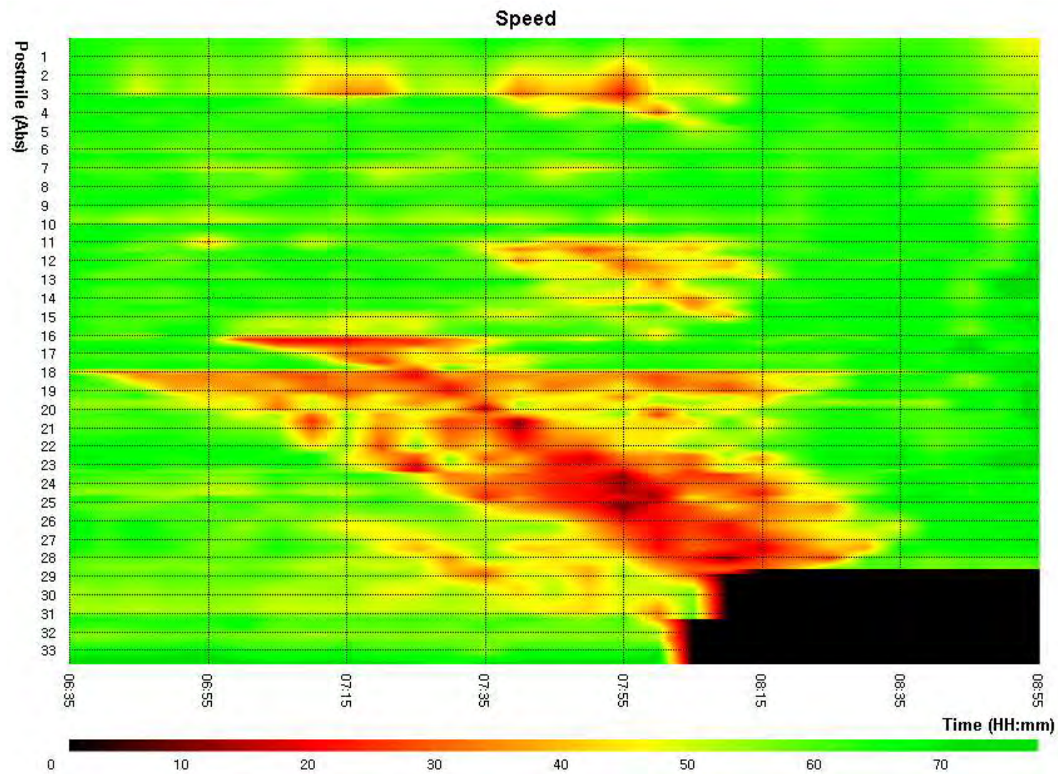


Figure 9-18: Speed contour for I-880, Scenario 3: Incident and 20% diversion

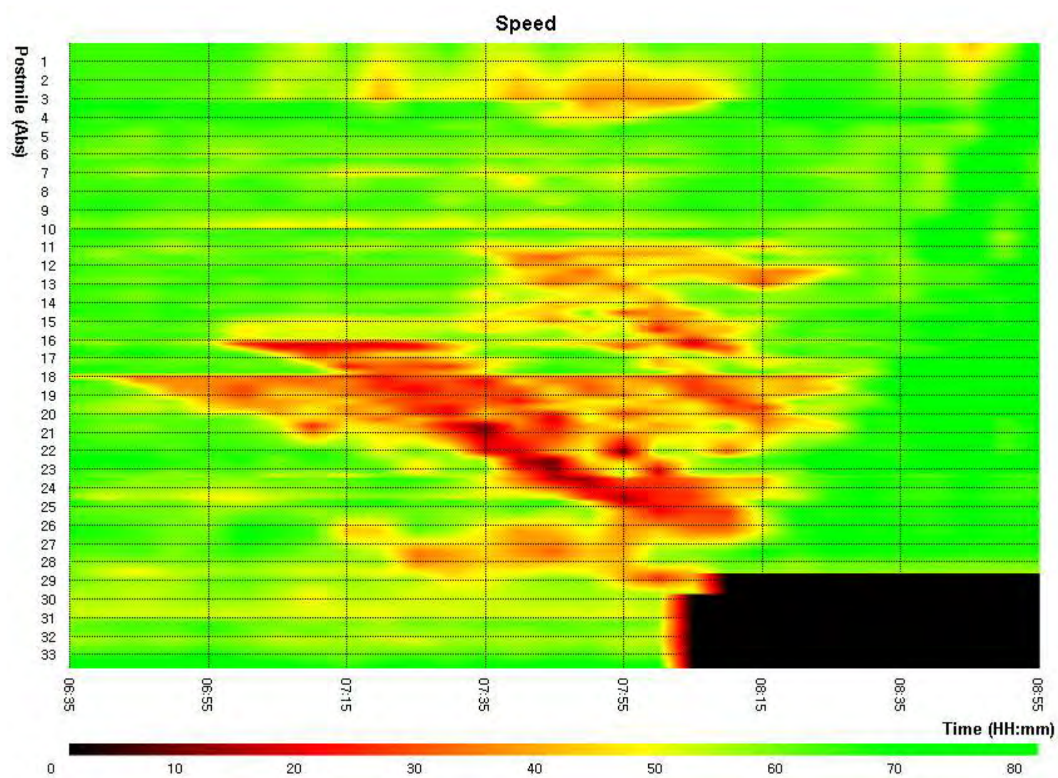


Figure 9-19: Speed contour for I-880, Scenario 4: Incident and 20% QID

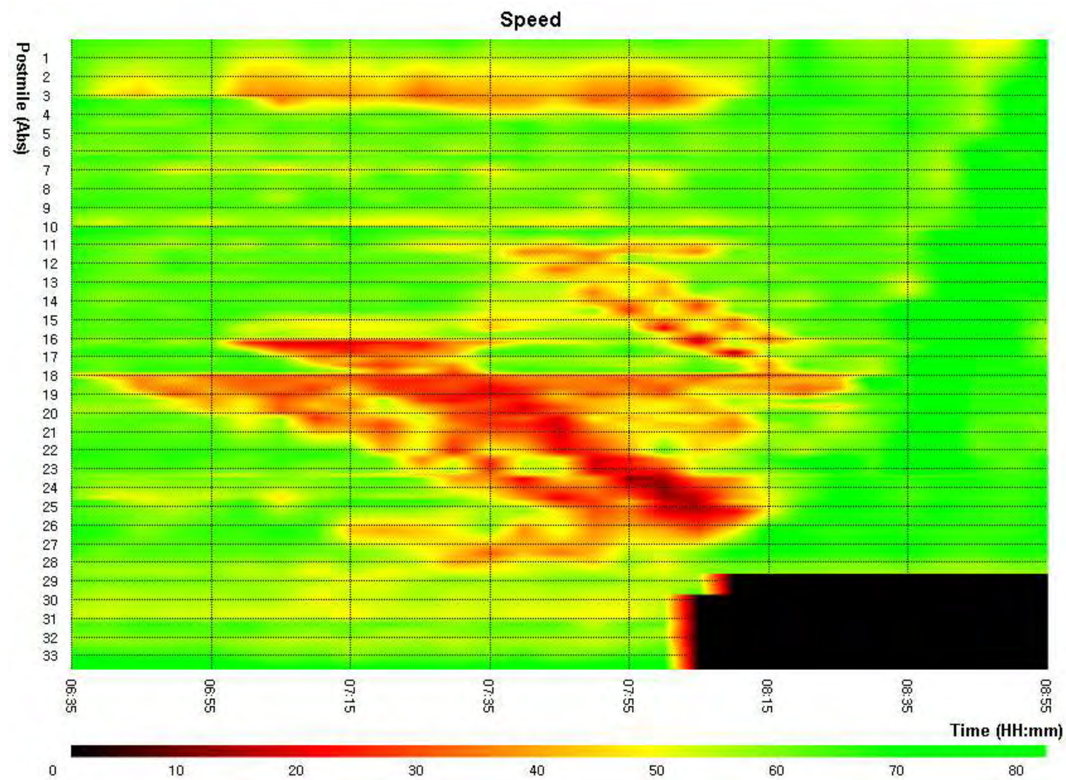


Figure 9-20: Speed contour for I-880, Scenario 5: Incident and 20% diversion and 20% QID

We can also measure the effect of the different diversion schemes by directly measuring the severity of the congestion based on the speed data. We arbitrarily choose 45 mph as the threshold for severity; that is, any speed below 45 mph is regarded as severely congested. The severity of congestion, which is measured in mile*hr, is calculated as the space-time area on the speed contour map that has speeds lower than 45 mph. Therefore, by measuring the area of "severe congestion," we can compare different scenarios more quantitatively. Figure 9-21 and Figure 9-22 show the effects of different CMS diversion rate and different QID level for self diversion on the severity of congestion. Figure 9-21 shows that incident makes the congestion much more severe, increasing the severity by 7.4% on the network. However, all the CMS diversion schemes show great benefit in terms of severity of congestion (though based on observation from speed contour map, they didn't reduce the queue length much). The 10% CMS diversion case yields the best improvement, which is about 11.6% compared with the no-diversion scenario. Interestingly, it is even better than the no-incident scenario.

Figure 9-22 gives more insight into the effects of different QID levels. We applied 20% diversion for all the scenarios with incident. While 5% QID is the base case, it is increased in the scenarios by 5% a step up to 25%. Compared with the base QID case (i.e. the second point), it shows that increasing the QID level generally has a positive effect on the congestion. However, there seems to be an optimal QID level, which, when exceeded, does not improve the congestion. In our simulations, 15% familiarity turns out to provide the best results in terms of severity of congestion.

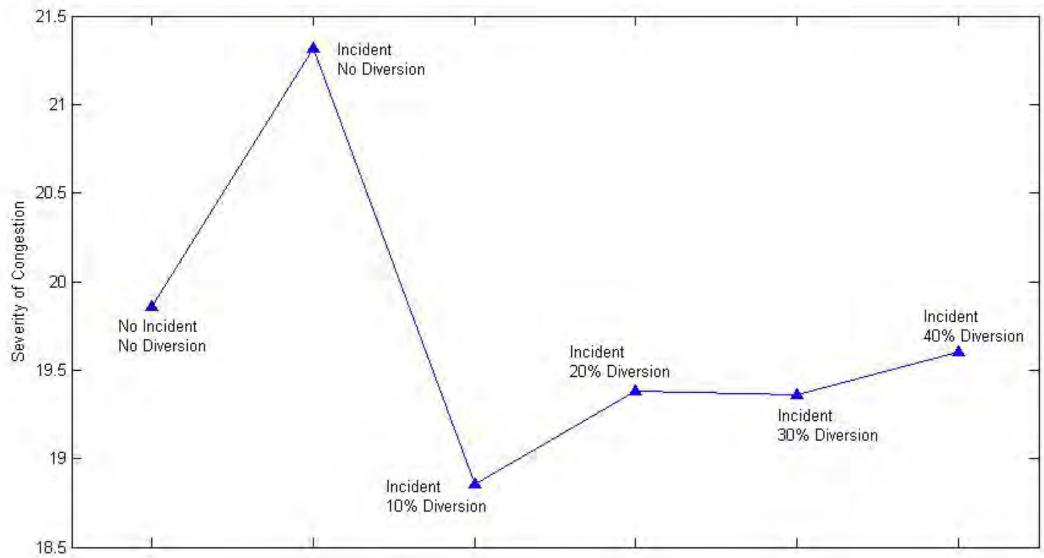


Figure 9-21: Severity of congestion for different diversion rates

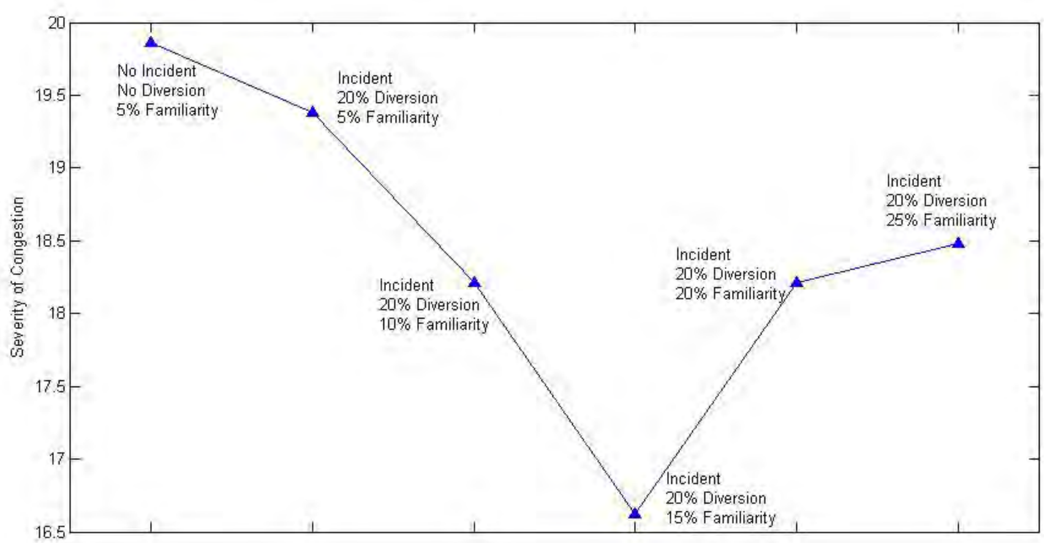


Figure 9-22: Severity of congestion for different QID levels

9.3.2.3 BOTTLENECK THROUGHPUT

Another interesting question that we want to look into is whether the TMC schemes can improve the bottleneck capacity. The capacity of the bottleneck is measured at the downstream of the bottleneck location, and when the bottleneck is activated. This results in congested traffic upstream and free flow traffic downstream. Since the new bottleneck is located at around PM 16, we should measure traffic immediately downstream of this location. We have an ideal loop detector set up for the network, which is located at PM 16.06. An examination of occupancy data for this loop detector shows that traffic has been in a free flow state all the time during the bottleneck activation (occupancy is below 15%). We measured the average outflow for the bottleneck for all the scenarios during 7:00-7:30. As shown in Figure 9-23, capacity of this bottleneck (or these bottlenecks, more accurately) drops greatly after the incident occurs, since two lanes are closed. The drop on average is over 20% of the previous capacity. (Note that the median lane is an HOV lane and is not fully utilized, which may explain the relative small capacity of this bottleneck.) Encouragingly, the CMS diversion schemes all show some improvement for the bottleneck capacity over the no-diversion scenario (holding QID the same across all scenarios). The 20% CMS diversion scenario gives the largest improvement, which is over 7% compared with no-diversion scenario, as shown in Figure 9-23. This is very encouraging considering most ramp-metering schemes only aim for an increase of 5%-10% over the bottleneck capacity[7].

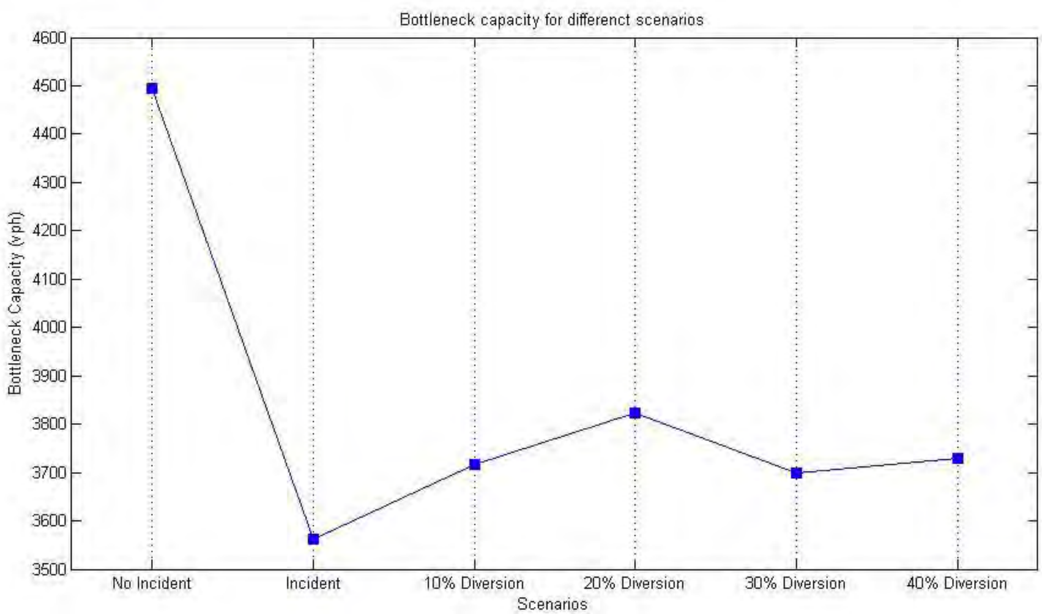


Figure 9-23: Bottleneck outflows for difference scenarios

9.3.2.4 VEHICLE EMISSION AND ENERGY CONSUMPTION

The CMEM plug-in, developed by UC Riverside, was set up to collect the emission and fuel consumption data. We mainly focus on green house gas (GHG), i.e. CO2, and fuel consumption. Similarly, first the effect of diversion on emission and fuel consumption will be investigated, followed by a comparison of different familiarity levels.

Figure 9-24 and Figure 9-25 show CO2 emissions and fuel consumption respectively under different CMS diversion rates. These two items generally follow the same trend. Incident increases the CO2 emission and fuel consumption; and a proper CMS diversion rate helps reduce both of them. 10% of CMS diversion gives the best values (2.9%

[7] Chu, L., Liu X., Recker, W., Zhang, H.M. (2004) Performance Evaluating of Adaptive Ramp Metering Algorithms Using Microscopic Traffic Simulation Model, Journal of Transportation Engineering, vol.130 (3), pp. 330-338.

reduction from no-diversion scenario). However, it is notable that when diversion rate is further increased, CO2 and fuel consumption rise significantly. This occurs as more vehicles use the local streets, which have lower speed limits and require frequent stops at intersections and signal lights. Therefore, when an excessive number of vehicles are diverted from the freeway to local streets, they will unavoidably consume more fuel.

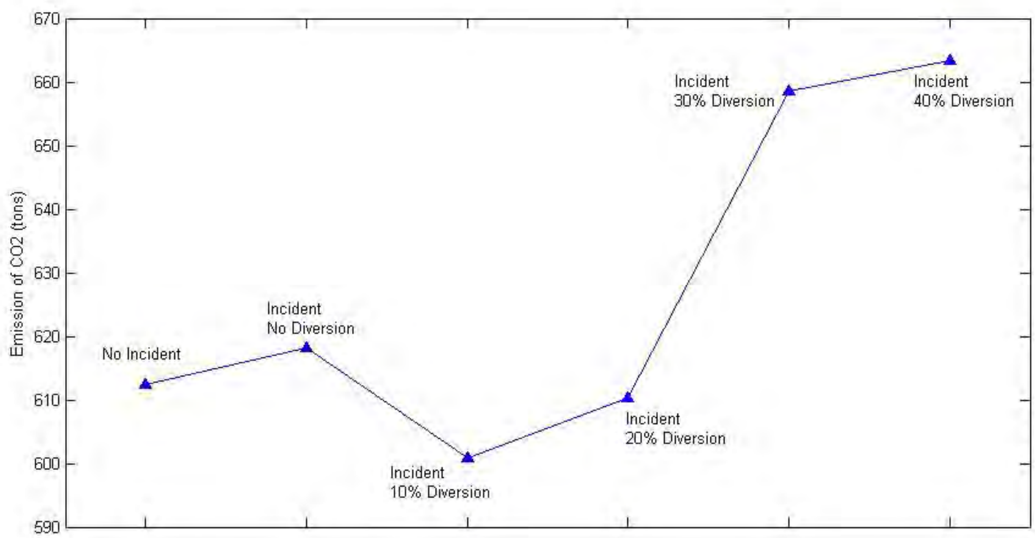


Figure 9-24: CO2 Emissions for different CMS diversion rate

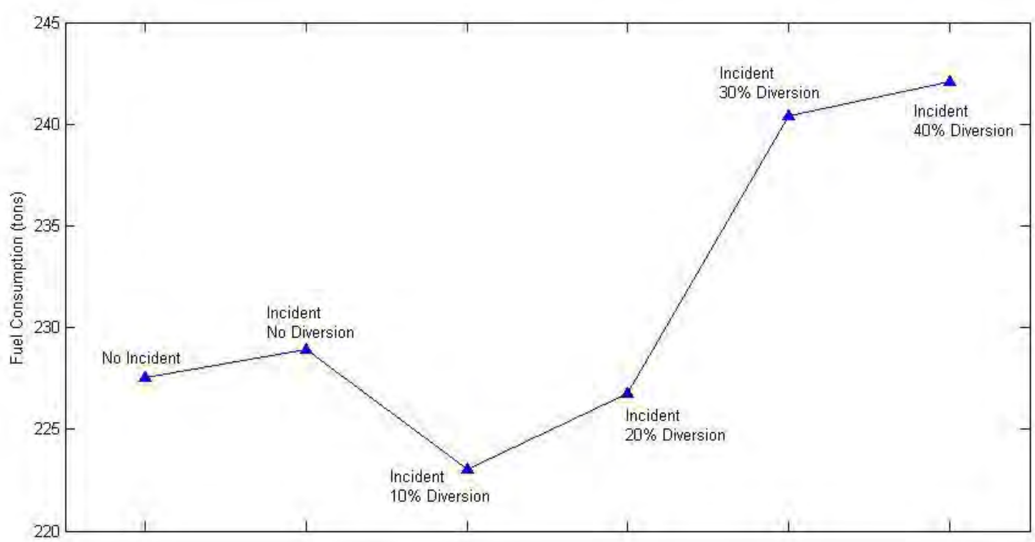


Figure 9-25: Fuel consumption for different CMS diversion rate

Figure 9-26 and Figure 9-27 show that increasing QID can generally help relieve CO2 emission as well as reduce fuel consumption. This is reasonable as more drivers are informed of the traffic conditions, more of them will choose the routes that are “most efficient” for them, which may contribute to an overall benefit for energy consumption.

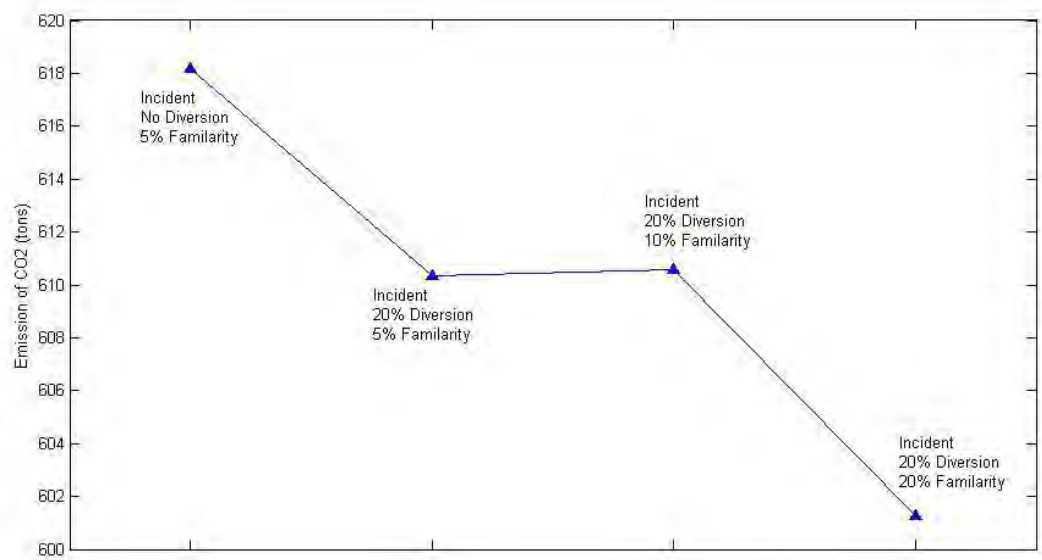


Figure 9-26: CO2 Emission for different QID level self-diversion

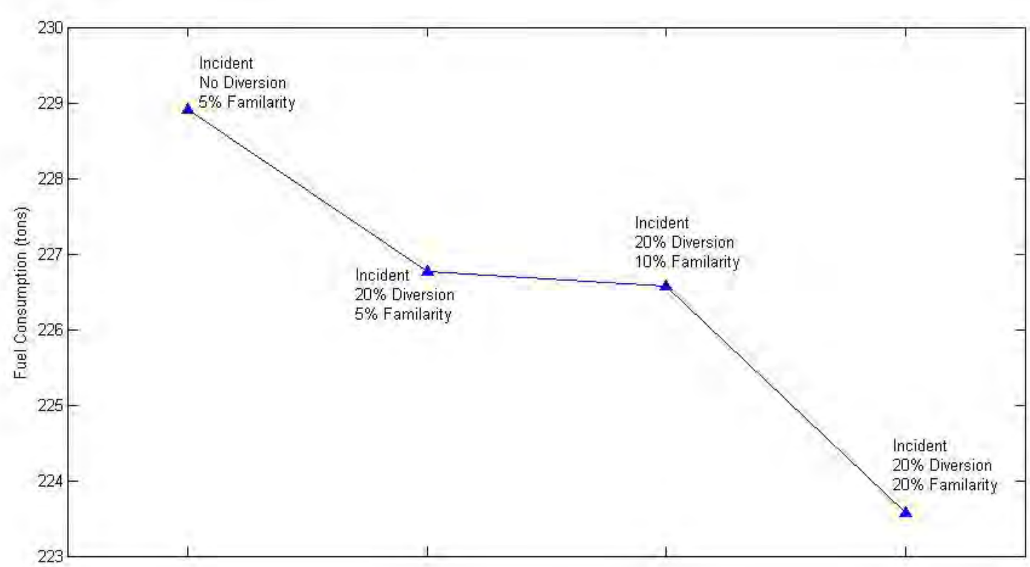


Figure 9-27: Fuel consumption for different QID level self-diversion

9.4 STUDY LIMITATIONS

The main constraint for the study was the scope of the model, namely, the study site, the incident location, etc. The I-880 is the only well-calibrated network and only one suitable incident location was identified for the study based on the available CMS. Therefore, some of the quantitative results from the simulation may be site specific.

Also, since the calibrated network did not include every possible street that exits, the simulation scenarios may not reflect the real-world situation.

Lastly, though the demands we used in the network are calibrated from real-world data, we did not include the effect of possible future demand change on the network.

10 CONCLUSIONS AND RECOMMENDATIONS

We have two main parts in our study: the survey study (for intangible benefits) and the simulation analysis (for tangible benefits).

We found that in general, commuters value the traffic information available to them and many of them agree that traffic information helps them to reduce travel stress. Among the different elements, CMS and ramp metering achieved the most exposure, and were also perceived to be more useful compared to 511 phone service and HAR, which had fewer frequent users based on our survey respondents. In terms of the ITS field elements' effect on diversion, the surveys found that commuters are unlikely to take alternate routes, unless they receive very strong traffic delay information or they are provided with more tangible benefits, i.e., travel time or financial savings.

The simulation study focuses on the use of an I-880 Paramics simulation model to evaluate the effectiveness of traffic information related field elements. Different diversion scenarios under the occurrence of an incident during the morning peak period were simulated. Simulation results showed that both CMS-based diversion and 511-based self-diversion are effective to improve system level performance and efficiency, relieve congestion, increase bottleneck capacity, and reduce emissions and energy consumption. Further analysis found that 20% CMS diversion makes the network reach an optimum state. Diversion rates higher than 20% CMS diversion rates do not add any benefit. The incorporation of self diversion helps the system to further improve its performance. The best diversion scheme could be a combination of 10%-20% CMS diversion rate and 15%-20% QID level self-diversion.

11 DEPLOYMENT

The continuation of this project to extend the survey coverage to other urban areas such as San Francisco Bay Area and Los Angeles as well as rural areas can shed more lights into general commuter perception regarding CMS, 511 and HAR benefits.

The simulation showed that both the 511 phone service and HAR system have a very high market coverage level, however, there are much fewer actual users of 511/HAR compared with CMS according to the survey. In this sense, increasing the market coverage and user awareness may help improve the usage level.

Other dissemination methods should also be considered. For example, according to the survey results, personalized traffic information via email or SMS alerts is of great interest to some survey respondents, who felt the information would help them plan their trip or efficiently respond to traffic congestion.

In addition, information provided on current field elements is not satisfactory to many drivers. More detailed and instructional information needs to be provided. For example, drivers prefer to have travel time available on CMSs all the time instead of only during traffic congestion; and drivers prefer travel time information and diversion instruction in case of congestion.

The study confirms positive attitude and responsiveness of commuters to ITS elements as well as tangible benefits demonstrated by the simulation results. The outcomes can support and justify statewide deployment of ITS. However, the implementation of new elements has to be incorporated with public awareness to maximize the effectiveness on commuter behavior.

12 REFERENCES

1) Dudek, C.L. Changeable Message Signs—Synthesis of Highway Practice 61. National Cooperative Highway Research Program, 1979.

2) CCIT. http://www.calccit.org/itsdecision/serv_and_tech/Traveler_information/Enroute/har_summary.html.

3) CCIT. http://www.calccit.org/itsdecision/serv_and_tech/list.html.

4) U.S. DOT – ITS. http://www.itsdeployment.its.dot.gov/Results.asp?ID=302.

5) 511 general information. http://www.fhwa.dot.gov/trafficinfo/511.htm.

6) Ramp Management and Control handbook. http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/default.htm. FHWA. 2006.

7) John M. Mounce, Gerald Ullman, GezaPesti, and ValmonPezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

8) Peeta S, Zhang P, Zhou W. Behavior-based analysis of freeway car-truck interactions and related mitigation strategies. Transportation Research Part B 2005;39(5):417-451.

9) ITS Performance and Benefit Study. National ITS Architecture. http://www.iteris.com/itsarch/documents/perfben/perfben.pdf. 1996.

10) Smiley A. Behavioral Adaptation, Safety, and Intelligent Transportation Systems. Transportation Research Record 2000;1724:47-51.

11) Asad J. Khattak, Felipe Targa, YoungbinYim. Advanced Traveler Information Systems: Relationship to Traveler Behavior, Chapter 12 in Assessing the Costs and Benefits of Intelligent Transportation Systems, Kluwer Academic Publishers, Edited by D. Gillen and D. Levinson, 2004, pp. 218-240.

12) Ben-Akiva M, de Palma A, Kaysi I. Dynamic network models and driver information systems. Transportation Research Part A 1991;25:251-266.

13) Khattak AJ, Schofer JL, Koppelman FS. Commuters' Enroute Diversion and Return Decisions: Analysis and Implications for Advanced Traveler Information Systems. Transportation Research Part A 1993;27A(2):101-111.

14) Adler JL, Blue VJ. Toward the Design of Intelligent Traveler Information Systems. Transportation Research Part C: Emerging Technologies 1998;6(3):157-172.

15) FHWA. IDAS: Intelligent Transportation Systems Deployment Analysis System. In: Cambridge Systematics, Inc.; 1997.

16) Program ITS. DynaMIT: Real Time Traffic Estimation and Prediction System. In: Intelligent Transportation Systems Program, Massachusetts Institute of Technology.

17) Mahmassani HS, Sbayti H, Zhou X. DYNASMART-P Version 1.0 User's Guide. In: Maryland Transportation Initiative, University of Maryland; 2004.

18) Gardes T, Lunsford ME, May AD, Van Aerde M. Application of the INTEGRATION model to demonstrate the simulation of advanced traveler information systems. In: Transportation Research Board Annual Meeting; 1993; Washington, DC; 1993.

19) Quadstone. PARAMICS Modeller V3.0 User Guide. Edinburgh, UK: QuadstoneLimitied; 2000.

20) Levinson D. The value of advanced traveler information systems for route choice. Transportation Research Part C: Emerging Technologies 2003;11(1):75-87.

21) Al-Deek HM, Khattak AJ, Thananjeyan P. A combined traveler behavior and system performance model with advanced traveler information systems. Transportation Research Part A: Policy and Practice 1998;32(7):479-493.

22) Arnott R, de Palma A, Lindsey R. Does providing information to drivers reduce traffic congestion? Transportation Research Part A 1991;25:309-318.

23) Kanafani A, Al-Deek HM. A simple model for route guidance benefits. Transportation research Part B 1991;25(3):191-201.

24) Chen PS, Mahmassani H. A dynamic interactive simulator for the study of commuter behavior under real-time traffic information supply strategies. In: Annual Meeting of Transportation Research Board; 1993; Washington, DC; 1993.

25) RITA-ITS, ITS Deployment Statistics. http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM.

26) CCIT. Travel Times on Changeable Message Signs in District 4 – Commuter Survey Report. July 2006.

27) K. Chatterjee, N. B. Hounsell, P. E. Firmin, P. W. Bonsal.l Driver response to variable message sign information in London. Transportation Research Part C: Emerging Technologies, Volume 10, Issue 2, April 2002, Pages 149-169.

28) Rong-Chang Jou, Soi-Hoi Lam, Yu-Hsin Liu, Ke-Hong Chen, Route switching behavior on freeways with the provision of different types of real-time traffic information. Transportation Research Part A: Policy and Practice. Volume 39, Issue 5, June 2005, Pages 445-461.

13 APPENDIX I –EXPANDED LITERATURE REVIEW

13.1 BACKGROUND

Based on both work plans listed in the research proposal and major action items discussed in the kick off meeting, the research team has conducted two sets of literature reviews, which, together with assistance from the Caltrans Technical Advisory Group (TAG) later on, will help the research team and Caltrans practitioners clearly understand current practices, possible gaps, unknown factors related to the operation and evaluation of information and control ITS field elements. Note: Our focused traveler group is commuters; in other words, ITS field elements' effects on commuters is the main topic of this research.

One aspect of the literature review is looking into current common practices of information and control of ITS field elements at a statewide, nationwide, or even worldwide scope. Various types of ITS field element applications, associated benefits, lessons learned, existing guidelines, etc., will be examined in order to understand effective ways of using ITS field elements that inform travelers, help their daily travel decisions, and optimize their travel patterns. These results will be further combined with the information and insights collected from Caltrans TAG to guide next steps of the research work.

The second part of the literature review is concerned with existing and potential methods to evaluate current practices of ITS field elements. The review encompasses both qualitative studies on general opinions regarding the usefulness of ITS field elements, and quantitative studies on existing models used to identify the numerical benefit of ITS field elements. Existing research findings on public perceptions or traveler responses to information and control ITS field elements will be reviewed. Route-choice models for traffic diversion using simulation tools will also beintroduced. In addition, barriers and challenges in the evaluation process of ITS field elements are also discussed, providing various insights to both researchers and practitioners in terms of future improvements on design, operation, management, and evaluation of ITS field elements.

13.2 CURRENT PRACTICE

Over the past several decades, common practices of information and control ITS field elements have been continuously promoted across theU.S., mainly due to the increased demand on but limited capacity of the network. Table 13-1shows the national summary of ITS deployments in 2006. This table presents a comparison of how the various types of field elements have been deployed throughout the country.

Table 13-1. 2006 ITS Deployments – National Summary (108 metropolitan areas surveyed)

Freeway Management	Reported	Total	Percent
Miles under electronic surveillance	7288	19470	37%
Ramps controlled by ramp meter	4102	26336	16%
Miles under lane control	956	19470	5%
Number of Dynamic Message Signs (CMS)	3398	N/A	N/A
Miles covered by Highway Advisory Radio(HAR)	4004	19470	21%

Note: Highlights from the 2006 Deployment Tracking Database[i]

In this study, information and control ITS field elements are primarily defined as:

- Changeable Message Signs (CMS, fixed or portable)

- Highway Advisory Radio (HAR)
- Call-in portion of 511 travel information service (providing en-route traveler information)
- Ramp metering (its effects on commuter trips)

13.2.1 CHANGEABLE MESSAGE SIGNS

Changeable Message Signs (CMS), also called Dynamic Message Signs or Variable Message Signs, can be effective tools in sharing real-time traffic information to the motoring public. A benefit of CMS installations is to reduce the delay and risks caused by incidents, construction, or other non-recurring delays[ii]. CMS can also inform travelers by helping them assess traffic, allowing them to make better route decisions, and alleviating traffic stress. Generally, CMS come in different varieties that can display several different types of messages, primarily based on the needs and goals of the traffic operations of the regions. For instance, CMS could display:

- Traffic information and travel times
- AMBER Alerts and safety messages
- Homeland Security information

Benefits will vary depending upon the intended use of the CMS, its location (e.g., urban versus rural), and its period of use[iii].

In 2004, a memo was release by the FHWA stating that[iv],

> “Over the years, transportation agencies have invested millions of dollars to acquire and install Dynamic Message Signs (DMS) as ways to provide information to motorists en-route. Based on the numbers of DMS reported in the 2002 Intelligent Transportation Systems (ITS) deployment tracking database, at least $330,000,000 have been spent on DMS. During adverse road conditions, traffic incidents and construction the signs have been used very effectively.”

The memo goes on to recommend practices for the use of CMS (or DMS):

> “We want to encourage the locations that are not currently providing travel time messages on DMS to investigate doing so. Travel time messages are not appropriate for every location, but they have proven successful in regions or corridors that experience periods of recurring congestion - congestion generally resulting from traffic demand exceeding available capacity and not caused by any specific event such as a traffic incident, road construction, or a lane closure. The DMS can provide dynamic travel time information instead of providing generic messages such as ‘congestion ahead’ or ‘stay alert’."

The FHWA believes that CMS is clearly an important device in aiding in the safe and efficient movement of people and goods through the transportation network[v]. The CMS is an outstanding example of ITS using computing and communications technologies to support traffic management and provide travel information directly to the audience that needs it most[vi]. While CMS have been in use for years, improving technology and a changing climate has necessitated, or provided the opportunity for, greater and more diverse use of CMS[vii]. However, there is a balance to be struck between the varieties of new uses possible for CMS with practices that are best suited to the use of these devices[viii].

The FHWA produced a handbook in 2004 titled, “Changeable Message Sign Operation and Messaging Handbook.” It recommends the following three primary issues related to messaging that need to be addressed when considering CMS[ix]:

- The basis for the message, i.e., what condition is occurring? What segment or region is impacted? What outcome or driver response is desired?
- How the content was determined, i.e., how is the message structured to maximize driver comprehension? Is the message aimed at commuters, unfamiliar drivers, or other groups? Is the content automated or put together by a TMC operator? How is the message coordinated with other information dissemination techniques, e.g. 511?
- What policies govern the display of messages, i.e. whose authority is needed to initiate a message? What are the arrangements for posting, updating, and terminating a message? What is the process for inter-agency coordination (especially with non-transportation agencies)? How are messages prioritized during periods when multiple messages are desired? How are 24/7 operations ensured?[x]

In general, the next generations of signs are capable of displaying images and/or varying text size. In Asia and Europe, some CMS have been displaying maps especially for their urbanized area. In the U.S., graphics in the form of interstate and state highway shields were introduced many years ago and were well received by the motoring public[xi].The advantages of good graphics/symbols are that the information can be read and understood more quickly and further upstream of the sign in comparison to word messages. Symbols may also be helpful to those motorists with poor reading skills. Research by Huchingson et al. (1978) showed that motorists exhibited a strong preference for having the route marker displayed (e.g., interstate shield) on the CMS in comparison to the written version (e.g., I-295)[xii]. However, the shape and color requirements in the Manual on Uniform Traffic Control Devices (MUTCD) suggest that the common types of symbols for regulation and warning cannot be used on current types of CMS[xiii,xiv]. Nevertheless, technology is rapidly changing, and research relative to graphics and symbols is advised in order to prepare for the arrival of the newer technologies on CMS[xv].

13.2.1.1 DESCRIPTION/APPLICATIONS

Dudek has organized four main categories in which CMS are used in traffic management[xvi]:

- Recurring problems, including everyday situations, such as peak traffic congestion, and planned traffic disturbances, such as special events;
- Nonrecurring problems, e.g., incidents, accidents, temporary freeway blockages, and maintenance;
- Environmental problems, including rain, ice, snow, and fog; and
- Special operational problems (including the operation of directional lanes, tunnels, bridges, tollbooths and weigh stations, etc.).

There is a general consensus that CMS have been deployed to provide information regarding traffic conditions to the public, and messages related to homeland security that do not refer to anything traffic-related don't fit this mold. AMBER alerts are widely recognized as the acceptable exception to this rule; homeland security messages are not generally considered a viable exception[xvii]. CMS have been widely deployed throughout the U.S. as shown in the chart below (Figure 9-1)[xviii], which shows the increasing rate of deployment in the U.S.

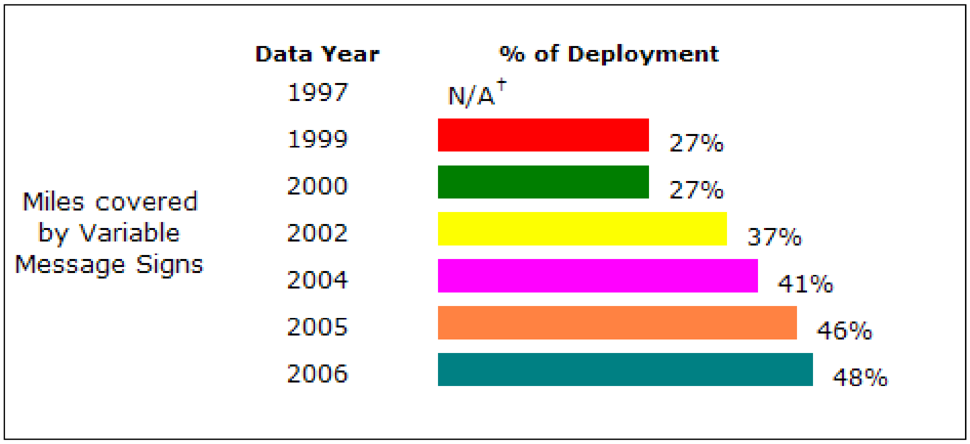


Figure 13-1. CMS Deployments by miles covered[xix]

13.2.1.1.1 TRAVEL TIMES

Travel time and delay messages are considered to be valuable information and an efficient use of CMS in the absence of adverse traffic incidents or events. Travel times (or delays) not only give the estimated time between a CMS and a point downstream, the presence of the travel time information gives the implicit message that there are no adverse conditions affecting traffic[xx]. It has been determined that displaying travel times involves careful process and operations, messaging, and policies in order to be effective. This information should incorporate as much automation as possible to optimize the use of valuable resources[xxi].

For instance, in California, expanding the scope and coverage of roadway travel times is a top priority of the *GoCalifornia* initiative. CMS display travel time information is gathered from a variety of means, including loop detectors, video detection systems, automatic vehicle identification transponders, and toll tags. An algorithm applied to field devices is used to calculate the distance covered to determine the estimated travel times from a CMS to specific destination, usually a major intersection and/or interchange, or in the case of toll tags, from one toll plaza to the next downstream toll plaza[xxii].

In addition, the FHWA reports that there are regions that are planning to implement static signs with a CMS insert panel, providing the motorist a static line of text referring to an upcoming intersection, with a live CMS panel that changes according to the automated data being fed to the sign, as illustrated in Figure 13-2 below[xxiii].

Figure 13-2. Static travel time sign

13.2.1.1.2 INCIDENTS/ROAD CLOSURES

Notifying drivers of incidents, crashes, or closures on the roadway is an important use of CMS because it can make motorists aware of upcoming incident conditions and give the opportunity to divert to alternate routes[xxiv]. Further, CMS messages can be used to warn motorists of significant delays or congestion on the roadway ahead unrelated to a specific incident. These warnings may be accompanied by suggested alternate routes or additional travel information[xxv]. Driver reactions to congestion, including diversion to alternate routes, are largely impacted by the degree of congestion ahead[xxvi]. These measures can be easily combined with travel time efforts to alert commuters of non-recurring congestion[xxvii].

The guidelines for the evaluation of dynamic message signs determined the following key points regarding the usefulness of CMS on incidents and road closures in their literature search[xxviii]:

- Support for common belief that about half of all congestion is induced by incidents;
- 60 percent of delay is directly linked to nonrecurring incidents and crashes - thus, with such significant traffic problems caused solely by incidents, it is necessary to promptly notify drivers of incident situations;
- Messages warning of en-route incidents may include information regarding the type of incident, location, or impacts on current traffic conditions;
- To determine the personal impact of the incidents and accidents, motorists desire exact locations to be displayed on CMS. This allows drivers to evaluate the effects of the incident on their individual travel time and route decisions.

13.2.1.1.3 SPECIAL EVENTS

Advance notice of a special event creating traffic or safety implications for travelers is often displayed on CMS[xxix]. This allows drivers to avoid congested areas during the scheduled event. Additionally, traffic control messages may be displayed to guide vehicles and lessen the severity of congestion[xxx].

13.2.1.1.4 AMBER ALERTS

Initiation of AMBER Alerts always rests with an emergency management or law enforcement agency such as State Police, or Office of Emergency Management (OEM). The amount of information available to law enforcement, and by extension to the DOT, can vary, and therefore make standardization a challenge[xxxi].

13.2.1.1.5 HOMELAND SECURITY

The use of CMS for homeland security or other emergencies of this nature is limited[xxxii]. Very few states or jurisdictions reported using CMS for any activity related to homeland security or emergencies of that nature, and those that did use CMS for this purpose used them rarely[xxxiii]. Policies and practices regarding the use of CMS for homeland security and related emergencies are still new, and information regarding policies and practices is still emerging[xxxiv]. The decision to post a message is in many cases handled by one agency, usually the state police or similar law enforcement agency; DOTs are one of the means by which homeland security messages are given to the public[xxxv].

13.2.1.2 BENEFITS AND LESSON LEARNED

Benefits achieved by CMS, including improved safety, time savings, increased throughput, cost savings, reduced emissions, and reduced fuel consumption, can be quantified to determine the effectiveness of the CMS[xxxvi]. It is also necessary to consider qualitative measures, such as customer satisfaction, when evaluating CMS. Consideration of the variables above can be used both to establish a framework for evaluation of CMS systems and to apply to the evaluation of the benefits of individual CMS in multiple settings[xxxvii].

An FHWA report highlights the lessons learned on Changeable Message Signs as follows[xxxviii]:

- ***Create a sense of urgency in order to convince drivers to comply*** - Experience of DOTs has shown that motorists don't respond as well to information given without a reason, e.g. "right lane closed." Giving the cause of the closure creates a greater sense of urgency and makes the motorist more likely to comply.
- ***Improve interstate coordination*** - Interstate coordination is typically an informal, non-standardized process. Some agencies utilize email to coordinate interstate CMS usage; some have contact numbers and make calls when the need arises. The process by which the controlling agencies communicate with each other should be standardized.
- ***Use paging conservatively*** - If a message requires more than one page, it is an important consideration that there is enough time for the traveler to read it.
- ***Aggressively maintain CMS*** - A CMS that does not receive regular maintenance, has non-operational bulbs, or has a transformer that does not work consistently, appears to the public as an expensive toy.
- ***Coordinate the placement and use of CMS along a corridor*** - If more than one CMS is available upstream from an incident, the sign furthest from the incident should be used to provide advance warning, thereby allowing drivers sufficient time to divert from the route. The sign closer to the incident should be used to control traffic flow nearer the incident.
- ***Always work to build credible and useful information*** - The value of CMS and the messages they display significantly influences their credibility.

Additional best practices for the use of CMS from several states are shared in a 2004 report from the U.S. DOT. Based on the experiences of several states, a few lessons have emerged related to providing an adequate and reliable message length that can serve as a basis for guidelines on CMS operations[xxxix]:

- Recognize the expectations of travelers when receiving information via CMS.
- Provide adequate information to ensure proper driver action.
- Limit messages to account for restricted driver reading times.
- Always work to build credible and useful information.

13.2.1.3 EXISTING GUIDELINES

Both transportation researchers and practitioners have prepared a number of guidelines on the use or operation of CMS over about two decades. Some are regional studies; for example, the North Carolina Department of Transportation (DOT) established their “Operational Guidelines for the Use of Changeable Message Signs” in 1995 and then updated it in 1999 because of the significant number of requests from various public groups[xl]; the New Jersey DOT supported the development of the “Variable Message Sign Operations Manual” from 1997 to 2001, which continues to be used as one of the most useful and practical references for CMS studies and practices. Some guidelines are nationwide; for example, the FHWA has released the "Changeable Message Signs Operation and Messaging Handbook" (CMS Handbook) in 2004, which is the latest comprehensive guidelines for CMS practices[xli].

Issues covered in these CMS operational guidelines generally include:

- **CMS operations policies** – there are typically federal level, state level, or even local level operations, policies, and guidelines that need to be followed. For example, the CMS Handbook (Dudek, 2004)has summarized that there are no written CMS operations policies at the national level; however, policies, standards, and guidance are embodied in the Manual on Uniform Traffic Control Devices (MUTCD)[xlii] and in several FHWA Policy Memorandums[xliii]. In addition, there is also a lack of region- and state-level CMS operations policies. Therefore, base on existing policy issues and statements from the New Jersey DOT Variable Message Sign Operations Manual[xliv], the CMS Handbook also presents examples/templates for 24 candidate policy issues.
- **CMS applications, issues, and operating fundamentals** – Many considerations need to be addressed before CMS are designed, deployed, and operated. For instance, various CMS applications are practiced in the real world,so it is important to determine the goal of using a CMS. There are basically two types of CMS – permanent or portable–so it is also necessary to decide which type is more appropriate; factors of optimal placement (i.e., location and distance) should be considered as well, e.g., operating speed of traffic, roadway vertical curves affecting sight distance, roadway horizontal curves, and obstructions such as trees, bridge abutments constraining sight distance, relative position of the sun, number and type of surrounding static guide signs, environmental characteristics such as frequency of snow, rain, fog, etc.
- **CMS message design** – This is a very crucial step in the whole CMS operation process. Issues might include type of messages, message type to avoid, priority of messages, maximum message length, size of characteristics and messages, etc. Special attention should be paid to long and dynamic messages. Some state guidelines even developed a library of standard messages[xlv]. Some examples of related issues from the CMS Handbook (*Dudek, 2004*) are list as follows:
  - Based on relative human factors principles for CMS operations, the author of the CMS Handbook consider "displaying messages only when unusual conditions exist on the freeway" as a better approach than "always displaying messages regardless of whether or not unusual conditions exist on the freeway". In other words, **Blank Signs** should be allowed.
  - A useful way to reduce the amount of time that the CMS are blank is to display **Travel Time**; however, its reliability and accuracy still remain questionable.
  - In terms of **Message Content**, the provided information should directly relate to motorists' forthcoming action; it should present problems, location, and also a clear reason for the message/action (e.g., major accident, roadwork, etc.); additionally, it's better to provide advice at the end of the message (e.g., merge left, take other routes, etc.). A balance is sought between the impacts of different elements. If one of these elements is overemphasized, the end result is that others may be neglected, or messages become too long or complex. Additionally, consistency in style and order allows the motorist to anticipate the message and allows them to focus on the element line that is of most importance to them. When more than one page/phase is available, messages are still often constructed to fit within one page to maximize readability.
  - **Message Length** should be determined by factors such as traffic speed, reading time, message familiarity, and so on. Based on some existing research results, it is recommended that the maximum message length for drives traveling at high speed should not exceed **eight words** in 18-inch characters; and no more than **three/four units** of information should be displayed on a

single message phase. To reduce message sign length, various approaches, e.g., acceptable abbreviations, avoid redundant words, partition of the message in two or more phases, might be used.

- In some states, the lines per page/phase range from 2 - 3 lines/units; characters per line from 16 - 28; and from 10 to 18 inches per character. Most signs are capable of using two pages; some signs can display even four consecutive pages; but many states insist that more than one page is not safe to display to drivers traveling at freeway speeds. Some signs are capable of providing more elaborate presentations: different fonts, flashing, centering, or making the text flush right or flush left.
- Guidelines regarding **sign readability** in some states call for a minimum of 900 feet of visibility, which translates to 8.8 seconds of viewing time at 70 mph or 11 seconds at 55 mph. One rule of thumb in practice when using CMS: there should be a minimum exposure time of at least two seconds per line. Arizona State University studied the legibility of various CMS in the Phoenix area and concluded that fiber optic CMS have an average legibility of approximately 835 feet. Subtracting 150 feet due to vehicle cut-off, where the sign is hidden to the driver due to the roof of the vehicle as the vehicle approaches the CMS,, leaves an average reading distance of 685 feet. Thus, motorists have approximately six seconds to comprehend a CMS message at 75 mph, or seven seconds at 65 mph.

- **CMS operation and maintenance principles** – this is generally a list and items that state DOT/local transportation operation agencies may want to include for the use of their daily CMS operation and maintenance.

In addition, in the beginning section of the FHWA's CMS Operation and Messaging Handbook, several additional basic references are listed for individuals in a management or supervisory position who have an interest in and/or responsibility for designing and displaying CMS messages[xlvi].

13.2.2 HIGHWAY ADVISORY RADIO

Highway Advisory Radio (HAR) has been used since in the beginning of the interstate system to notify the motoring public about travel hazards or other travel information[xlvii]. HAR uses AM radio frequencies that transmit between 1 and 6 miles in distance[xlviii]. These frequencies can be so strong that they overpower any other frequency transmitting to a powered radio. According to federal regulations, HAR broadcasts may not contain entertainment or commercial messages[xlix]

There are multiple technologies available for HAR application including Federal Communication Commission's (FCC) licensed 10-watt transmission, digital HAR, low-power AM transmission (no FCC license required), or in some cases HAR is operated with a FCC license under low-power FM transmission[l]. In addition, Automatic Highway Advisory Radio (AHAR) provides a method to overcome the need for HAR signs and manual tuning to the HAR frequency by sending out a leading message, which is picked up by a special in-vehicle receiver when the vehicle enters the AHAR zone[li]. The message automatically tunes the radio to the AHAR station and mutes any regular radio broadcast until the AHAR transmission is complete[lii].

Coordination with regional or multimodal traveler information efforts, as well as arterial and incident management programs, can increase the availability of HAR information on freeway travel conditions[liii].

13.2.2.1 DESCRIPTION/APPLICATIONS

In a 2006 national survey, it was found that HAR is deployed in 63 urban areas, yet only covers 21% of the freeway miles within those areas, as shown below in Figure 13-3[liv]. A typical roadside sign is displayed in Figure 13-4.

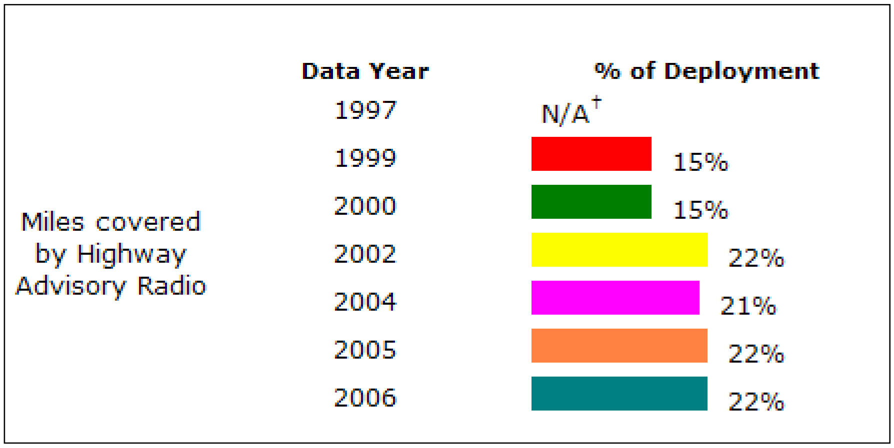


Figure 13-3. HAR Deployments by miles covered

Figure 13-4. Typical HAR roadside signage

HAR can be used to notify motorists of travel times, incidents, congestion, and special events. Specifically, Highway Advisory Radio informs travelers of[lv]:

- Detours
- Operating restrictions such as requirements to put on snow tires or chains
- Warnings about hazards such as forest fires, floods, mudslides, or highway closures
- Traffic conditions along short segments of specific routes, especially work zones
- Directions to tourist attractions
- Parking availability
- Public transit alternatives
- Notices of events.

Additionally, many turnpikes, toll facilities (tunnels, bridges), and other “closed” systems such as airports, causeways and national parks use HAR[lvi]. It is also used to broadcast changing conditions in long-term construction sites that have a large share of repeat visitors[lvii].

13.2.2.2 BENEFITS AND LESSON LEARNED

HAR is an important element of emergency/disaster preparedness and response. In a 2006 FHWA report titled, "Integration of Emergency and Weather Elements into Transportation Management Centers," HAR is considered to be one of the current methods used by TMC operators to mitigate congestion by providing timely and accurate travel information to travelers[lviii]. However, there are various advantages and disadvantages to an HAR implementation.

Its most important advantage is that it can reach more travelers, or potential travelers, than CMS. While CMS reach only those motorists at a particular point and can only convey a short message, HAR has the advantage of being able to communicate with any person in its broadcast range and the amount of information that can be conveyed is much greater[lix].

In 2004, a study in the mountainous region of Spokane, Washington, revealed that commercial truckers found HAR effective[lx]:

"During the post deployment period, 39 CVOs were surveyed and asked, "Has the availability of HARs, camera images of key roadway segments, and enhanced Internet information affected driving safety for you in this region compared with last year?"

- Eleven of the respondents said they did not know whether their drivers used these information sources, or they themselves did not use them.
- Of the remaining 28 CVOs, 16 (57%) said the availability of the new information made them "somewhat" or "a lot" safer.
- The remainder (12 CVOs, 43%) said the safety benefit to them was "about the same as before." No one reported a reduction in safety.

Its primary disadvantages are that it is restricted to low power, and this leads quite often to poor signal quality, and it requires the driver to take an action; these factors can lead to poor listenership of HAR[lxi, lxii]. In addition, keeping the information current is labor-intensive; under some conditions, placing, installing, and maintaining antennas can be costly, as can staffing and equipping a central control facility to coordinate information from multiple agencies[lxiii].

The ITS Decision website notes several additional challenges, besides cost, to implementing a HAR system. These include following[lxiv]:

- Making travelers aware of the service because frequencies change so often and cover such small territories
- Designing the message, which must be succinct yet comprehensive
- Maintaining AM signals at a quality that is e*njoyable to listen to*

13.2.2.3 EXISTING GUIDELINES

Based on the extent of our reference search, various national- and state-level HAR related guidelines have been developed over the last two decades. For example, the FHWA published its "System Analysis and Design Guidelines for Highway Advisory Radio" in 1981[lxv]. Many states, e.g., Virginia, New York, Colorado, etc., have prepared their own HAR guidelines[lxvi].

In general, all guidelines point out that transportation professions and traffic operators should develop a comprehensive HAR message template/library in advance to conduct efficient traffic management and control, not only for planned special events but also for non-recurrent unusual roadway conditions. Table 13-2 shows the example of possible HAR message considerations from the FHWA report – Managing Travel for Planned Special Events[lxvii]. The report pointed out other related principles. For example by taking into consideration travel speed and HAR signal range, HAR messages should be appropriately formatted so that motorists can listen to each message at least twice; also, it might be important to ensure portable HAR (when needed) coverage areas do not overlap with adjacent HAR signals.

Table 13-2. Highway Advisory Radio Message Considerations

Pre-Event Message Considerations	Day-of-Event Message Considerations
— Planned special event(s) date, time, and location — Road closure(s) location — Road closure(s) date and time — Traffic and parking restrictions — Alternate routes and modes of travel	—Directions to local traffic flow routes serving traffic destined to a venue — Road closure details — Event traffic and parking restrictions

Moreover, as the Virginia DOT HAR operational guidelines stated, an integrated HAR guidelines might also consider different aspects of operations, such as personnel, transmitter placement, advisory signing, message development, and equipment maintenance, etc[lxviii]. It particularly highlighted the process and factors of message design:

- Message should include short attention statement, brief description of the problem or event, location of the problem/event, reason for following the advisory, advisory, and so on;
- Messages are recommended to be limited to 60 seconds. Avoid wordy messages to make sure drivers are able to hear all the information being broadcast.
- As route descriptors, using route name is better than route numbers to identify roadways according to human factors.

The guidelines additionally provide the sample messages for various traffic situations, which should be a very useful reference for other transportation agencies to develop their own HAR operational guidelines.

13.2.3 511 TRAVELER INFORMATION SERVICES

13.2.3.1 DESCRIPTION/APPLICATIONS

A recent innovation in traveler information services is 511, a national three-digit telephone number designated exclusively for traveler information. The 511 Deployment Coalition was established in early 2001 to facilitate nationwide development. And as of March 2007, thirty-four 511 services in 30 states are operational. A few metropolitan or regional level 511 services are located in Florida and California[lxix]. 511 has been used for both pre-trip and en-route information through telephone and Internet service.

The Deployment Coalition appears to be the leader in promoting the deployment of 511 systems[lxx]. This coalition is led by the American Association of State Highway Transportation Officials (AASHTO), in close cooperation with more than 30 public agencies, industry groups, industry associations, and private companies from around the country[lxxi]. As of September 2007 many regions of the U.S. have deployed 511 systems; this is shown by the 511 Deployment Coalition shown in Figure 9-5. Figure 9-6 tracks how these deployments have grown over time.

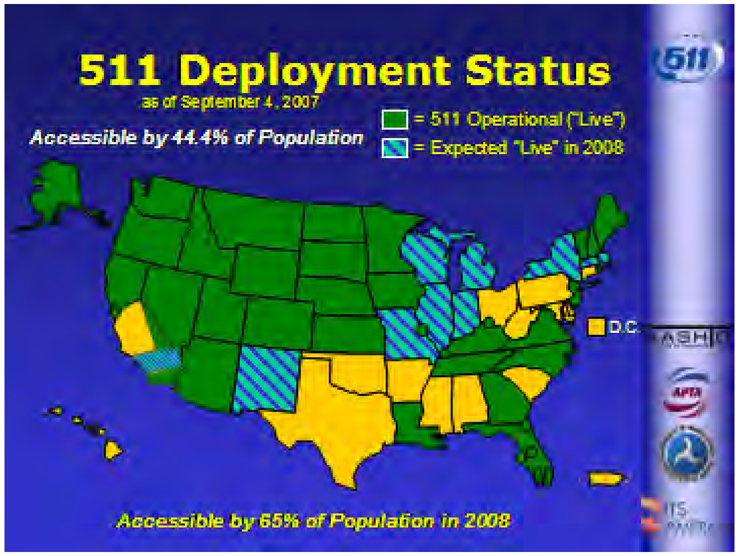


Figure 13-5. 511 Deployment status[lxxii]

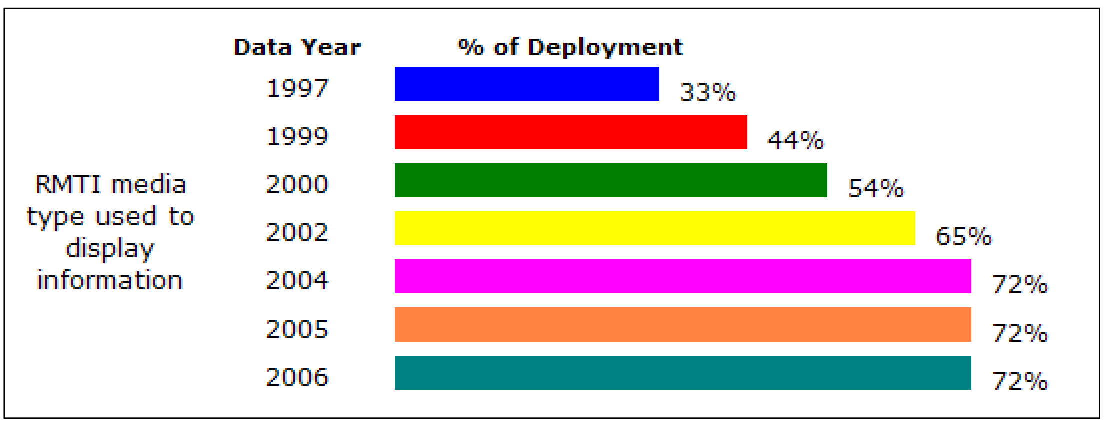


Figure 13-6. Deployments of regional multimodal traveler information (511)[lxxiii]

13.2.3.2 BENEFITS AND LESSON LEARNED

A 511 system's usage is one measure of effectiveness. If it works well, it will be well used. Benefits that customers receive from using 511 have surfaced in formal research, such as focus groups and surveys, and also through customer comments and through coverage of 511 by the media[lxxiv]. Among the many features and benefits identified, those considered important to 511 users were[lxxv]:

- Ease of use and convenience
- Real-time, accurate, quality road and traffic conditions
- Avoiding traffic congestion and road construction
- Weather information
- Reducing frustration and relieving stress
- Helping users to make informed travel choices
- Changing travel behavior including altering routes and departure times
- Saving time and lives
- Receiving information about tourism and other services

The ITS office of the U.S. DOT has reported on several policy and planning related benefits of implementing 511 systems, offering lessons from collective experience. These include[lxxvi]:

- Perform local consumer research on the 511 service during the planning stage of the project [lxxvii, lxxviii]
- Consider the future when planning and deploying a traveler information system[lxxix, lxxx]
- Clearly define roles, responsibilities, plans, and processes[lxxxi]
- Encourage private sector involvement to help reduce program risk and support on-time deployment[lxxxii, lxxxiii]
- Educate tourist-oriented businesses and tourism organizations about the economic benefits of ITS[lxxxiv, lxxxv]
- Incorporate mechanisms for capturing user feedback for system evaluation, including the ability to intercept incoming 511 calls for survey or focus group recruitment[lxxxvi, lxxxvii]
- Recognize that interoperability is becoming an important issue in achieving the vision of a nationwide 511 system[lxxxviii, lxxxix]

The 511 deployment coalition tracks usages statistics for each month for each 511 system; some go back as far as 5 years[xc]. Over time the usage shows that peak usage was experienced due to weather conditions and AMBER Alerts[xci]. In a 2002 survey of 511 deployment evaluations in the SF Bay Area reveled an assortment of usage statistics from the telephone and companion websites[xcii]. In 2005, the 511 coalition reported that system monitoring can be divided into three primary categories: usage, reliability, and accuracy. The following statistics are recommended for use[xciii]:

- **Monitor system usage:**
  - Calls Per Month
  - Peak Call Day, Count, and Reason
  - Peak Call Hour, Count, Date, and Reason
  - Highest Simultaneous # of Ports
  - Number of Regular Users
  - Average Call Length (Seconds)
  - Maximum Call Length
  - Percent Wireless and Landline
  - Percent Calls from Service Area
  - Percent Category
  - Caller Comments
- **Monitor system reliability:**
  - Comparing the system availability with a pre-determined standard.
- **Monitor system accuracy:**
  - Sample incidents (or non-reports) and determining for a specific period, whether 511 was providing accurate information.

Furthermore, the coalition reports that "this lesson learned highlights the need for deployers to monitor their 511 system"[xciv]. System monitoring assists deployers in better managing their projects and in ensuring customer satisfaction[xcv]. Through system monitoring, deployers can track the performance of their service against pre-determined standards, and can address any issues or problems that arise[xcvi]. Moreover, the usage data provides the Deployment Coalition with a means for understanding nationally the full scope and impact of 511[xcvii].

13.2.3.3 EXISTING GUIDELINES

Prepared by 511 Deployment Coalition, the latest version of 511 guidelines, titled "Implementation and Operational Guidelines for 511 Services, Final Draft Version 3.0," was published in July 2005The guidelines begin with a brief history of 511 traveler information services and an introduction to 511 deployment coalition; then the proposed 511 vision statement and vision elements are explained. In the main body of the document, the 511 implementation and operational guidelines are explained comprehensively in eight subsections.

- Overarching guidelines – Prior to any successful deployment and operation of a 511 service, some overarching issues, such as business environment, system interoperability, privacy, national ITS architecture, standards, safety, etc., should be paid serious attention. Some specific examples are:
  - Basic 511 telephone services should be no more than the cost of a local call and websites should be made available to all Internet users. Although advertising and sponsorship, as well as fee-generating premium or enhanced services, are acceptable, they need to be appropriately screened.
  - Different existing 511 systems have three basic options for interoperability: call transfer, data transfer, and application sharing.
  - All 511 services should adhere to ITS America's Fair Information and Privacy Principles, to prevent any privacy issues, which is available onthe ITS America website.
- Content guidelines – Basic content requirements/suggestion for roadway traffic and transit information are discussed in this subsection. In addition, general issues related to content quality are also addressed here. Some specific examples are:
  - Quality factors that need to be considered include accuracy, timeliness, reliability, consistency of presentation, relevance, etc.
  - Basic roadway content includes construction/maintenance, road closures and major delays, major special events, weather and road surface conditions, etc. Detailed description for each type of content should contain information such as location, direction of travel, general description and impact, days/hours and/or durations, travel time or delay, detours/restrictions/routing advice, etc.
  - For transit content, 511 should be able to provide a brief description of surrounding agencies' operations, major service disruptions, changes or additions, and also an option to be transferred to local agency's customer service.
- Telephone guidelines – This subsection covers specific guidelines for 511 phone service, such as call routing, possible 511 phone service access, call transfer, etc. Some examples are:
  - Seamless and reliable call routing is required for a successful 511 service, which should go virtually unnoticed by the user.
  - The caller should be notified when being transferred out of the local 511 service. In general, 511 deployers should use call transfers to provide a comprehensive 511 service when appropriate and/or necessary either functionally or financially.
- 511 user interface guidelines:
  - It is recommended to use voice recognition as the primary user interface.
  - It is also recommended to have a parallel touch-tone menu as a back-up to the interactive voice menu.
- Service quality and access guidelines:
  - A good 511 service should be sized to accept all calls for the 90th percentile peak hour load, in order to achieve the ability to reliably and quickly answer calls.

  - 511 services should be available to travelers 24 hours a day, 7 days a week.
  - 511 services should also consider people with disabilities, multilingual and environmental justice issues, etc.
- Website guidelines:
  - The basic content requirements on a co-branded 511 website should be similar to the information offered on the 511 telephone service.
  - It will be much better to add graphical representation (e.g., GIS) through website information dissemination channel.
  - Another critical part that could be added to a travel information website is arepresentation of real traffic conditions via traffic cameras.
- System monitoring guidelines – This is a crucial function for effectively and efficiently managing the 511 system, which contains three primary system categories: usage, reliability, and accuracy.
- Marketing and evaluation guidelines – This subsection helps deployers to either generate thegeneral public's awareness and use of 511 for travel information, or understand people's opinion/feedback of 511 services.

13.2.4 RAMP METERING

13.2.4.1 DESCRIPTION/APPLICATIONS

Ramp metering is the use of traffic signals at freeway on-ramps to control the rate of vehicles entering the freeway[xcviii]. The metering rate is set to optimize freeway flow and minimize congestion; the metering rate can be fixed, or responsive to local or system-wide conditions[xcix]. Signal timing algorithms and real-time data from mainline loop detectors are often used for more effective results[c]. Figure 13-7 offers a diagram of a typical ramp metering application. Data is collected from in-road sensors and sent to the traffic management center; once a certain congestion level is reached, the ramp metering is activated. Queue detectors alert the traffic management center when the queue is spilling out into the arterial streets.

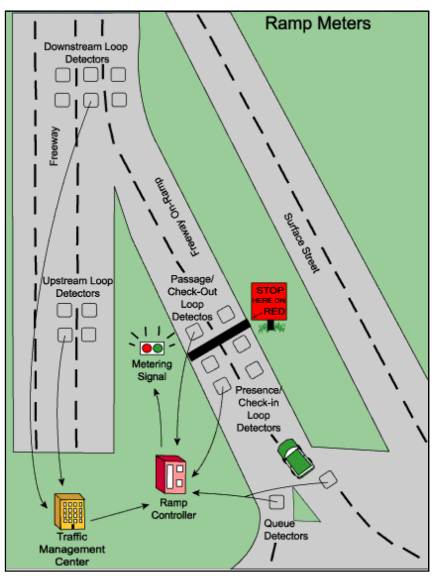


Figure 13-7. Ramp metering diagram[ci]

13.2.4.2 BENEFITS AND LESSON LEARNED

The meters are utilized as part of our current transportation system. The current ramp meters improve safety, save energy, reduce congestion, minimize environmental impacts, and enhance mobility[cii]. Ramp meters are an inexpensive tool to improve traffic flow on freeways. Ramp meters allow traffic to enter the freeway at a rate dependent on the conditions of the freeway traffic. While a typical driver might be delayed at the meter, overall travel and freeway speeds are improved. The metering system's four primary benefits are[ciii,civ]:

- Lateral efficiency – better use of entire corridor's width
- Longitudinal efficiency – higher efficiency over the entire corridor's length
- Time efficiency – shortened traffic peak period
- Travel time savings – the ability to make quicker trips
- Effective use of capacity – making the best use of the existing roadways
- Reduced travel time variability – having a better idea of when you will arrive
- Safety – reduced number of accidents in the vicinity of the meter installation.

In other words, it improves transportation thatdirectly impacts our state's economic landscape[cv]. Congestion monitoring data provides a system performance tool to planners and decision makers to improve existing facilities and prioritize future projects[cvi].

13.2.4.3 EXISTING GUIDELINES

Nationwide, the FHWA released "Ramp Management and Control Handbook" (Ramp Handbook) in January 2006[cvii]. This latest version of ramp management and control guidelines complements in greater depth the ramp management and control issues and concepts that were presented in Chapter 7 of the Freeway Management and Operations Handbook[cviii], which were published in September 2003, also by the FHWA. Some state DOTs also prepared their own ramp metering guidelines, such as California[cix], Colorado[cx], and others.

As stated in the Ramp Handbook, ramp metering can be an effective tool to address congestion and safety concerns by using traffic signals to control the flow of traffic entering a freeway facility. However, many issues should be given serious attention prior to the implementation of any ramp meters, such as:

- Metering strategy – Practitioners need to review and determine the goals and objectives that metering is intended to address when developing a specific metering strategy. In addition, the strategy should integrate all issues and concerns that might be affected by the implementation of certain metering(s) from a much broader transportation management perspective.
- Geographic Extent – It is important to determine the area that will be covered by ramp metering and whether the meters in that area will be operated in an isolated manner or in a linked pattern (i.e., as part of a larger system of meters).
- Metering Approaches – There are different metering approaches according to the Ramp Handbook, such as local or system-wide metering, pre-timed or traffic-responsive metering, metering at demand, operator selection of meter rate, etc.
- Metering Algorithms – The Ramp Handbook also provide examples of the specific logic and calculations used to select or determine a metering rate, which has been successfully used in many states' practices.
- Queue Management – This is an important concern that needs to be addressed in the ramp metering implementation process – how the metering rate will be affected by ramp queues and how the agency will keep queues at a manageable and acceptable level.

- Flow Control – Not surprisingly, it is also very necessary to determine how traffic will be released from the meter, e.g., one at a time or two at a time in one lane or multiple lanes.
- Signing – This is an aspect of human factors – how to design the signing system to make sure drivers will know that a ramp meter is on or off.

13.3 EVALUATION OF CURRENT PRACTICE

13.3.1 ITS FIELD ELEMENTS EVALUATION CONSIDERATIONS

Prior to initiating any performance evaluation, many factors should be considered to shape the overall evaluation[cxi]. Thoughtful consideration of these factors will better ensure that the evaluation results are relevant to the objectives, technically valid, and appropriate to the intended audience. This section summarizes some important considerations that some researchers and practitioners have been taking into account in their performance evaluation process. These considerations are a very useful reference to further develop our own information and control ITS field elements evaluation processes.

13.3.1.1 TYPES OF APPLICATIONS

It is imperative that researchers and practitioners consider different types of ITS field elements applications before conducting any performance evaluation[cxii]. The reason is that there are numerous applications for the various ITS field elements. Different types of applications might have different effects on both individual travelers and on the transportation system as a whole; therefore, different benefits would be found and different evaluation methods would be required.

Information and control ITS field elements generally aim to advise travelers with real-time traffic conditions, suggest alternate travel routes or travel modes, and reduce traffic stress, However, different emphases of usages could be found from different types of applications. For instance, in the early stage of applying ITS technologies, Dudek[cxiii] has categorized four types of traffic related applications for Changeable Message Signs:

- Recurring
- Nonrecurring
- Environmental
- Special operational problems

For recurring problems such as peak traffic congestion, the major objective might be to inform travelers of real-time traffic information and reduce their traffic stress; here, user satisfaction would be an important performance measure in the evaluation process. However, for special operational problems, the primary goal of ITS field elements would be to detour partial or entire traffic from the construction route to alternative routes or modes, where system-wide reduction of travel time/delay would be highlighted in the evaluation.

Although our major target is commuter trips in this study, there are still significant needs to consider different goals and effects associated with different types of applications.

13.3.1.2 TYPES OF ROAD USER GROUPS

Before starting the ITS field elements evaluation process, it is necessary to understand travel behaviors and characteristics associated with different types of road user groups. The differences are as follows:

- Different types of road users might have different responses to similar information provided by a control ITS field element because of their particular travel behaviors and circumstances[cxiv]. For example, commuters tend to pay more attention to ITS field elements; and at the same time they are more likely to respond to different ITS field elements applications[cxv].Conversely, large-truck drivers may have a lower tendency to divert than motorists in incident situations, and their re-routing might be subject to trucking firms' priorities or particular information from trucking companies[cxvi].
- Different types of vehicles may also have particular impacts on different traffic conditions, such as incident-induced congestion. For instance, the share of large vehicles (e.g., commercial vehicles) in the traffic could be a statistically significant factor affecting incident occurrence[cxvii]. In addition, components of traffic flow such as percentage of heavy duty vehicles may influence incident duration, i.e., large trucks may interfere more with incident clearance operations[cxviii].
- Network performance imposes different costs on different types of road users. Traffic congestion is more costly for businesses than individual travelers, especially for the situation of incident-induced congestion[cxix]. In addition to driver cost of delay, the negative impacts of traffic congestion on businesses could be late incoming/outgoing deliveries, and the cost of keeping additional inventory. Nevertheless, there is also significant cost placed by cars and roadways to individual travelers, to the transportation system, and to the society and environment as well. In other words, the magnitude of benefits coming from effective operation of ITS field elements is significant but different for different road user groups.

Therefore, instead of isolating the effort only to the commuter side during the course of modeling, developing, and evaluating ITS field elements, it will also be worthwhile to take into account other types of user groups when possible.

13.3.1.3 STUDY AREA OF EVALUATION

Another consideration that should be addressed before moving to the evaluation process is the identification of study area. There are obviously different goals and levels of intensity for the use of ITS field elements in different areas. For example, in urban areas, CMS are typically used to inform motorists with dynamic traffic conditions (i.e., expected delays, estimated travel times, diversion routes, lane closures, etc.) and have become an important source of travel information during incidents, special events, and work zone traffic control. In rural areas, the focus of CMS utilization is usually for displaying timely roadway and environmental conditions to enhance motorist safety[cxx]. Therefore, the benefits of information and control ITS field elements will vary depending upon not only the intended use of the elements (as reviewed above) but also its location (e.g., urban or rural, local or regional, etc.).

The selection of study area can also have significant implications for the data needs, evaluation techniques, resource requirements, and even the results[cxxi]. ITS field element applications can have impacts beyond the local area in which they are implemented. For instance, depending on real traffic conditions, impacts may be observed at freeway bottleneck locations downstream from ITS field elements themselves, arterial intersections located many miles from the freeways, or even on alternative modes such as transit[cxxii]. Therefore, in order to ensure the proper assessment of system impacts, it is important to identify an appropriate study area prior to the implementation of the evaluation effort.

Based on the purpose and extent of the study, as well as other factors like data/resource availability and analysis tool availability, the study area could be generally classified into three categories: localized, corridor, or regional[cxxiii]:

- Localized analysis focuses on the impacts observed on the facilities immediately adjacent to the field elements and is more appropriate for evaluations focused on a narrowly defined set of performance measures;
- Corridor analysis expands the study area to the corridor level, which is more appropriate when the deployment is anticipated to affect some of the performance measures along an entire corridor, or when multiple field element locations are involved;
- A regional study area is more appropriate when a comprehensive accounting of all possible impacts is required, or when the deployments are scattered across a large area.

In our study, we will address this consideration by first discussing the common and general issues and principles of information and control ITS field elements evaluation with broader and regional view; and then selecting several study areas to do the detailed localized or corridor analysis.

13.3.2 PERFORMANCE MEASURES

According to the explanation from the FHWA's "Freeway Management and Operations Handbook"[cxxiv], performance measures are used to measure how the transportation system performs across a variety of criteria: all performance measures need to be able to provide the basis for evaluating the effectiveness of the implemented freeway facilities, field elements, management strategies, etc.; performance measures also need to be able to track changes in system performance over time, identify the need for improvements and enhancements in systems or corridors, and provide information to decision-makers and the public[cxxv].

There are many measures of effectiveness for ITS field elements. The CMS guidelines report prepared by Texas Transportation Institute (TTI) includes a comprehensive compilation of ITS measures and metrics(Figure13-8).

I. Improve operational efficiency and capacity A. Measures of transportation infrastructure and capacity use 1. Traffic flows 2. Lane capacity 3. Volume to capacity ratios 4. Incident-related capacity restrictions 5. Intermodal transfer times and delays B Measures of congestion 1. Vehicle-hours of delay 2. Queue lengths 3. Time spent in queue 4. Number of stops 5. Throughput 6. Traffic speeds C. Measure of vehicle capacity and use 1. Average vehicle occupancy 2. Use of transit and high-occupancy vehicle (HOV) modes D. Measures of operating cost efficiency 1. Infrastructure costs 2. Vehicle operating costs 3. Fare collection and reduction 4. Freight operating costs	**II. Enhance mobility, convenience, and comfort** A. Number of trips taken B. Individual travel time C. Individual travel time variability D. Congestion and incident-related delay E. Travel cost F. Vehicle miles traveled (VMT) G. Number of trip end opportunities H. Number of accidents I. Number of security incidents J. Exposure to accidents and incidents K. Customer satisfaction 1. Perceived stress reduction 2. Perceived increased convenience L. Freight movement costs 1. More reliable "just-in-time" delivery 2. Travel time and cost 3. Driver fatigue and stress 4. Cargo security 5. Safety of hazardous cargo 6. Transaction costs
III. Improve safety A. Number of incidents B. Number of accidents C. Number of vehicle thefts D. Number of injuries E. Number of fatalities F. Time between incident and notification G. Time between notification and response H. Time between response and arrival at scene I. Time between arrival and clearance J. Medical costs K. Property damage L. Insurance costs M. Personal security	**IV. Reduce energy consumption and environmental costs** A. Vehicle emissions 1. NOx emissions 2. SOx emissions 3. CO emissions 4. VOC emissions B. Liters of fuel consumed C. Vehicle fuel efficiency D. Emissions and consumption of fuel can be measured by 1. Travel time 2. Queuing time 3. Number of stops 4. Number of accelerations 5. Kilometers/miles traveled 6. Speeds E. Noise pollution F. Neighborhood traffic intrusiveness
V. Increase the economic productivity of individuals, organizations, and the economy as a whole A. Travel time savings B. Capital cost savings C. Operating cost savings D. Maintenance cost savings E. Administrative and regulatory cost savings F. Manpower savings G. Savings in labor hours H. Vehicle maintenance and depreciation I. Information-gathering costs J. Sharing of incident and congestion information K. Integration of transportation systems L. Ability to evolve M. Cost savings	**VI. Create an environment in which the development and deployment of ITS can flourish** A. ITS sector jobs B. ITS sector output C. ITS sector exports

Figure13-8. Compilation of ITS measures and metric[cxxvi]

13.3.2.1 CATEGORIES OF PERFORMANCE MEASURES

There are several different categories of performance measures that have been defined by the FHWA, the National ITS Architecture[cxxvii], as well as many researchers and practitioners for ITS field element evaluation purposes[cxxviii]. Some of them are cited as follows:

- **Safety** is generally measured through changes in the number of crashes or incidents, segmented by severity or type (e.g., fatal/injury, accidents/disablements, etc.). Detailed measures might include number of crashes, number of fatalities, number of incidents, etc. Note: It might be more appropriate to evaluate the change in the crash rate (e.g., number of crashes per vehicle-mile traveled) rather than the actual number of observed crashes to help control for changes in traffic volumes over time.

- **Mobility** is typically measured as a change in travel time, speed, or delay, etc. These metrics intend to capture road users' travel experience, as well as the transportation network performance. How to use these measures appropriately for different purposes needs to be carefully considered. For instance, use of aggregate or system measures such as total system vehicle-miles-traveled (VMT) may not accurately capture individual users' benefits; however, disaggregate or spot measurements such as speed may not accurately reflect the system-wide benefits or individuals' overall travel experience.
- **Throughput** is used to represent the transportation system performance from the system operator's perspective and typically includes measures such as throughput (vehicle or person volumes), volume to capacity (V/C) ratio, queuing measures (length and frequency), bottleneck, level of service (LOS), etc.
- **Travel Time Reliability** is one of the innovative performance measures that has recently been developed for performance evaluation. A few examples[cxxix] include the travel time index (TTI), which is a comparison between the travel conditions in the peak-period to free-flow conditions; and the buffer time index (BTI), which expresses the amount of extra "buffer" time needed to be on time at your destination 95 percent of the time (e.g., late to work one day per month)[cxxx]. These performance measures are very important because more reliable travel time estimates allow travelers to better budget their travel schedules and eliminate the impact of expected and unexpected delays.
- **Environmental** performance measures used in ITS field elements evaluation typically contain changes in vehicle emissions, fuel consumption, and so on. In general, it is very challenging to come up with effective environmental performance measures that may be successfully evaluated within the available resources and transportation framework; therefore, additional consideration of data collection and analysis methodology development is necessary.
- **Public Perceptions/Acceptance** represents the perceptions of travelers regarding the effects of the ITS field elements and their acceptance of the system performance, which can be extremely important measurements depending on the purpose of the study. Generally, these measures can be assessed through conducting a series of one or more focus group interviews, telephone surveys, or panel survey groups, etc. The collection of this data often requires significant resources and time. Nevertheless, the information on public perceptions or user satisfactions gained through these methods can be invaluable in shaping public outreach efforts.

The primary goals of traffic information and control system research and practice are better management of traffic flow, enhanced driving conditions, and improved traveler safety, etc[cxxxi]. Based on the different categories of performance measures discussed above, as well as the understanding of the goals of the system, we will establish a comprehensive set of performance measures in our study.

13.3.3 EVALUATION METHODS

With appropriate performance measures selected, the benefits of ITS field elements can be evaluated through different evaluation methods. Benefits can usually be categorized as either tangible or intangible. Tangible benefits can be directly observed and possibly quantified, in which case a quantitative method should be employed. Intangible benefits generally cannot be quantified but are real and potentially significant, e.g., traffic stress; in this case, qualitative method should be used. These intangible benefits/costs are sometimes referred to with a shadow price[cxxxii].

In general, quantitative methods are more desirable during the common evaluation process, compared to qualitative methods, because results of quantitative methods tend to be more intuitive to all stakeholders including general public, and more comparable among different projects. However, the domain of this research project is information and controls ITS field elements whose end-users are the motoring public. So obviously, involved measures, such as commuter response, or travel behavior, etc., are often times intangible and very difficult to be connected to tangible/quantitative measures. Therefore, it is necessary for us to review both existing quantitative and qualitative evaluation methods, as well as the possible linkage between these two types of measures.

13.3.3.1 QUALITATIVE METHODS

For transportation researchers and practitioners, the initial interest and motivation in information and control ITS field elements is because of the human propensity to modify behavior to suit new conditions[cxxxiii]. We assume that adaptations in traveler behavior will occur when travelers are provided with dynamic traffic information or traffic control, which could benefit individual travelers as well as the whole road network. However, Smiley[cxxxiv] pointed out that one cannot simply look at changes in the targeted task, but rather at drivers' complex decision processes and their actual responses to traffic information/control in evaluating the related technologies.

Understanding traveler behavior is an important aspect for developing and evaluating ITS field elements; however, it usually requires analysis skills within the qualitative fields. Furthermore, public perception and acceptance are an important category of performance measures that help transportation researchers and practitioners understand the effectiveness of information and control ITS field elements. Again, these essential measurements generally require qualitative techniques to conduct the analysis. Definitive results can be achieved through observational studies in which people are given dynamic information and control and their responses are observed and reported[cxxxv]. However, it is expensive and difficult to design, conduct, and control an observation study in the real world.

According to existing literature, there are several experimental approaches to evaluating travel behavioral responses[cxxxvi]. Some measures could be typically evaluated through a series of one or more focus groups interviews, telephone surveys, or panel survey groups. For instance, we can ask people what they want and how they would react to proposed different services and attributes, which is called **stated preference (SP) approach**. SP is extremely useful for exploratory studies of new concepts and technologies or for understanding willingness to pay; however, sometimes it produces results that may not correspond to real behavior of traveling public. On the other hand, transportation researchers/practitioners also proposed **revealed preference (RP) approach**, in which people recall and report their real life travel behavior that happened a short time ago. This approach can actually take advantage of the periodical regional household survey by adding several traffic information and control related questions, such as several metropolitan areas have been done (e.g., the research triangle area in Raleigh-Durham-Chapel Hill, North Carolina, and Seattle, Washington)[cxxxvii]. In addition, transportation researchers have recently attempted to combine both SP and RP experimental approaches, where individuals either have the chance to choose from a given set of hypothetical scenarios or report their real life actions to dynamic traffic information and control[cxxxviii].

When relying on qualitative methods, as well as on the often-used descriptive and inferential statistic analysis techniques, several issues of potential behavior causal factors should be addressed[cxxxix] in the evaluation process, such as:

- How do people perceive information and control ITS field elements?

- How do travelers use the dynamic traffic information and control that they acquire?
- Why is dynamic traffic information and control important or travelers?
- What are the consequences of using ITS field elements?

13.3.3.2 QUANTITATIVE METHODS

There have been worldwide efforts during recent decades to study various aspects of dynamic traffic information and control technologies. One important aspect to evaluate is the impact of such technologies on travelers and the transportation system. In terms of providing dynamic traffic information and control (essentially, ITS field elements), many studies using qualitative methods have pointed out that ITS field elements could offer significant benefits to ameliorate traffic congestion, improve network performance, and enhance travel safety, thus providing economic and environmental advantages[cxl]. In recent decades, more ITS field elements have been implemented to support more informed travel decisions. There is a great demand for establishing more validated performance measures, especially quantitative methods, to identify the clear benefits and costs associated with ITS field elements.

Within the research/projects using quantitative methods, few studies utilize empirical traffic data, which can be difficult to collect. An example of using empirical traffic data is illustrated in a study conducted by Levinson and Huo, where they employed changes in real flow and occupancy data over time on both mainline and ramps (collected every 30second) to estimate the effectiveness of CMS. With the convenience of longitudinal real traffic data, they were able to conduct a before and after analysis to quantitatively evaluate the network wide reduction of travel time and total delay of CMS system[cxli].

However, due to the scarcity of field data on impacts of traffic information and control technologies, as well as the considerable higher cost associated with observational field study, researchers have modeled them in laboratory experiments and through simulations. Simulation tools that have been used for ITS field elements evaluation include IDAS, DynaMIT, DYNASMART-P, INTEGRATION, PARAMICS, etc[cxlii]. Although such models provide useful approaches to the study of evaluating ITS technologies, they still have some disadvantages. For example, they may not represent well the different road user groups. Furthermore, for some of the simulation models, especially microscopic ones, they also require a great amount of data, and are also very time- and manpower-consuming to conduct the whole system calibration and validation. Therefore, it is crucial for us to identify an appropriate tool based on the data sources and other factors that are available.

13.3.3.3 RELATIONSHIP BETWEEN QUALITATIVE AND QUANTITATIVE METHODS

Conceptual models of travelers' behavioral choices given traffic information and control information are efficient ways to establish the relationship between qualitative and quantitative evaluation methods that have been proposed by some researchers, including Haselkorn et al.[cxliii], Ben Akiva et al.[cxliv],Khattak et al.[cxlv], and Adler and Blue[cxlvi]. With regard to dynamic traffic information, they found that en-route diversion behavior was influenced by the source of traffic information, expected length of delay, regular travel time on the usual route, and anticipated congestion level on the alternative route as well. Hence, all these elements should be incorporated when evaluating dynamic traffic information and control systems.

In terms of the detailed statistical traveler choice models that have been proposed, they mainly include the following types of models[cxlvii]:

- Logit model

    - e.g., binary logit model, ordered logit model / multinomial logit model, mixed logit model / dynamic kernel logit model
- Probit (binary probit model, multinomial probit model, weighted probit model)
- Negative binomial model
- Ordinary Least Squares (OLS) model

Some of these models have been used only for qualitative interpretation purposes, while a few of them have been linked to quantitative analysis. In addition, researchers also pointed out (statistically) significant factors that affecting traveler response to traffic information and control systems, which generally include travelers' socioeconomic information (e.g., age, gender, income, education, etc.), information characteristics (e.g., source, content, attributes, etc.), travel contexts (e.g., trip purpose, trip length, time flexibility, etc.)[cxlviii].

Accounting for traveler behavior is a critical aspect in evaluating traffic information and control ITS field elements. Several relevant studies have already conducted simulation models or proposed theoretical frameworks with consideration of behavioral characteristics[cxlix]. However, there remains a weak connectivity between drivers' actual responses to traffic information/control and system performance modeling tools. Therefore, how to effectively design and conduct a qualitative study (i.e., behavioral survey analysis), and how to incorporate results from qualitative study into quantitative study (i.e., simulation analysis) are important issue to address.

13.3.4 EVALUATION CHALLENGES

From both the transportation researcher's side or from the transportation practitioner's side, many challenges still exist in evaluating traveler behavior, though the literature shows numerous attempts to evaluate dynamic traffic information and control systems. This section lists some of the potential major issues we will face during the process of evaluating information and control ITS field elements.

Conducting traveler behavioral surveys and performing statistical analyses are the most important and useful means of qualitative study, especially for behavioral analysis; there are many such kinds of studies that have been done for traveler information related analysis. However, most of them are from a broader view of traveler information system, where pre-trip information is one of the major concerns (to some extent, people consider this type of traveler information more useful than en-route one); and there are fewer studies that focus on en-route ITS-field-element-related traveler information. Nevertheless, the analysis methodology should have some similarities and could be used in our case. Then we need to come up with our new survey questionnaires as well as a novel analysis and interpretation method.

Monitoring the operation or performance of a freeway is critical for both the agency responsible for managing the facility and for the facility's users; performance monitoring is used to assess existing conditions for short-term non-recurring events, and for long-term recurring events[cl]. Traffic data, especially real-time data from ITS systems, is needed to effectively manage and operate a freeway[cli]. However, lack of data, either current or historical, is often the critical issue during the process of evaluation, e.g., conducting before and after analysis. In some situations, microscopic simulation could be one of the most effective ways to help the evaluation process. However, this approach may not be the best choice because microsimulations require a large amount of traffic data for the calibration process. Even with adequate amounts of data available, a microsimulation's accuracy and reliability remain questionable to many of the researcher and practitioners.

Assistance from practitioners' side would be very helpful[clii]. Therefore, it will be highly beneficial for us to set up a close partnership with Caltrans practitioners or even private professionals, and to more clearly understand the current practices, possible gaps, or unknown factors related to ITS field element operations. Furthermore, practitioners usually have thoughtful insights on existing technical barriers, system reliability, elements location requirement, operational barriers, user expectations, etc. In addition, they might also have some direct feedback from traveling public (if something is good, you may not hear anything; but if something is bad, you definitely will hear a lot of voices).

14 APPENDIX II – SURVEY QUESTIONNAIRE

Commuter Travel Survey

You are invited to take a quick survey regarding your usage of traffic information and control elements (e.g., Changeable Message Sign, Highway Advisory Radio, 511, ramp metering etc.). Your assistance is very important to us and it will help in the future planning and operation of traffic information and control elements in your region. Your responses will be kept strictly confidential. Thank you!

Commuting Trips

1. How often do you **commute by car** (i.e., daily travel between home and work/school)?
   - ❑ 4 times or more per week
   - ❑ 2 – 3 times per week
   - ❑ 0 – 1 time per week
   - ❑ I do not commute / I do not commute by car*

   *** If you checked this box, you may stop taking the survey.**

2. In what area does your commute usually begin? ______________ ______
   (Zip Code or Neighborhood) and (City Name)

3. In what area does your commute usually end? ______________ ______
   (Zip Code or Neighborhood) and (City Name)

4. How long have you experienced the above-mentioned commute origin and destination?
   - ❑ More than 5 years
   - ❑ 3 – 5 years
   - ❑ 1 – 2 years
   - ❑ Less than 1 year

5. What commute routes do you use most frequently? (e.g., I-5, CA-163)

   ____
   ____
   ____
   ____

6. What is your approximate one-way commute distance?
   - ❑ 60 miles or more
   - ❑ 45 – 59 miles
   - ❑ 30 – 44 miles
   - ❑ 15 – 29 miles
   - ❑ 5 – 14 miles
   - ❑ Less than 5 miles

7. What is your average one-way commute time?
   - ❑ 60 minutes or more
   - ❑ 45 – 59 minutes
   - ❑ 30 – 44 minutes
   - ❑ 20 – 29 minutes
   - ❑ 10 – 19 minutes
   - ❑ Less than 10 minutes

8. What is an acceptable amount of time you can be late to work/school? ____________ (Minutes)

En-Route Traffic Information and Control Elements

9. Have you seen/heard of any following **en-route** traffic information and control elements? (*Please check all that apply.*)
   - ❑ Changeable Message Sign (CMS)
   - ❑ Highway Advisory Radio (HAR)
   - ❑ 511 Phone Call
   - ❑ Ramp Metering
   - ❑ Others, please specify: ____________

10. How **often** do you use these traffic information and control elements for your commute?

	CMS	HAR	511	Ramp Metering
5 times or more a week	❑	❑	❑	❑
3 – 4 times a week	❑	❑	❑	❑
1 – 2 times a week	❑	❑	❑	❑
Never	❑	❑	❑	❑

11. For your commute, how would you rate the **usefulness** of these traffic information and control elements?

		CMS	HAR	511	Ramp Metering
Very Good ↑	5	❑	❑	❑	❑
Good	4	❑	❑	❑	❑
Fair	3	❑	❑	❑	❑
Poor	2	❑	❑	❑	❑
Very Poor	1	❑	❑	❑	❑

12. Do you think that traffic information generally helps you to reduce your travel stress?
   - ❑ Strongly agree
   - ❑ Agree
   - ❑ Neutral
   - ❑ Disagree
   - ❑ Strongly disagree

13. For CMS, what would be your preference in terms of travel time message display?
    - ❑ Display travel time all the time
    - ❑ Display travel time information only in case of traffic and congestion; otherwise blank
    - ❑ Others, please specify: ____________

En-Route Traffic Delay and Route Choice

14. During the past month, have you experienced a traffic delay longer than 10 minutes? If yes, how much time was it?
    - ❑ Yes
        - ❑ 11-20 minutes
        - ❑ 21-30 minutes
        - ❑ 31-45 minutes
        - ❑ 46-60 minutes
        - ❑ More than 60 minutes
    - ❑ No*

    *** If you checked this box, please skip to question 17.**

15. How did you receive the information on traffic delay?
    - ❑ Changeable Message Sign (CMS)
    - ❑ Highway Advisory Radio (HAR)
    - ❑ 511 Phone Call
    - ❑ Self observation of heavy congestion
    - ❑ Other (please specify) ____________

16. Did you take an alternate route (i.e., substantially different from your intended route) after getting the delay information?
    - ❑ Yes
    - ❑ No

17. In general, have you ever changed your typical commute route based on information you received from any of these **en-route** resources? (*Please check all that apply.*)
    - ❑ Yes. It's based on:
        - ❑ Changeable Message Sign (CMS)
        - ❑ Highway Advisory Radio (HAR)
        - ❑ 511 Phone Call
        - ❑ Other resource (please specify) ____________
    - ❑ No

18. When traffic information tells you that your typical commute route has a significant traffic delay, please indicate your willingness to use an alternate route.
    - ❑ Detour, if time saved by using an alternate route is:
        - ❑ about 0 – 5 minutes
        - ❑ about 6 –10 minutes
        - ❑ about 11 – 20 minutes
        - ❑ about 21 – 30 minutes

- ❑ about 31 – 45 minutes
- ❑ about 46 – 60 minutes
- ❑ more than 60 minutes

❑ Never divert

Other Commuter Travel Choices

19. Have you made any of the following changes to your typical commute behavior in the last 6 months based on traffic information you've received? *(Please check all that apply.)*
    - ❑ Leave earlier than originally planned
    - ❑ Leave later than originally planned
    - ❑ Participate in carpool/vanpool program
    - ❑ Pay a toll for using Express Lanes
    - ❑ Use public transportation
    - ❑ Change to another commute route
    - ❑ Work from home/Telecommute
    - ❑ Others (please specify) ____________

20. Have you heard of RideLink carpool or vanpool program?
    - ❑ Yes
        - ❑ I've used it before.
        - ❑ But I haven't used it.
    - ❑ No

Please respond to the following statement, indicating your level of agreement.

21. For my commute, I like to participate in carpool, vanpool, or pay a toll for Express Lanes.

	Carpool	Vanpool	Toll for Express Lanes
Strongly agree	❑	❑	❑
Agree	❑	❑	❑
Neutral	❑	❑	❑
Disagree	❑	❑	❑
Strongly disagree	❑	❑	❑

22. Have you ever changed your commute behavior because of the ramp metering?
    - ❑ Yes, I used different ramps to access freeways.
    - ❑ Yes, I changed my departure time.
    - ❑ No.
    - ❑ I don't know.

Socioeconomic Information

23. Your gender:
    - ❑ Female
    - ❑ Male

24. Your age group:

- ☐ Under 18
- ☐ 18 – 24
- ☐ 25 – 34
- ☐ 35 – 49
- ☐ 50 – 64
- ☐ 65 or above

25. Your approximate household income:
    - ☐ Under $25,000
    - ☐ $25,000 – $44,999
    - ☐ $45,000 – $74,999
    - ☐ $75,000 – $149,999
    - ☐ $150,000 or above

26. What is the highest level of education you have completed?
    - ☐ High school or less
    - ☐ College
    - ☐ Graduate school or higher
    - ☐ Other (please specify) ____________

27. We would appreciate your comments (optional): ______________________________

____

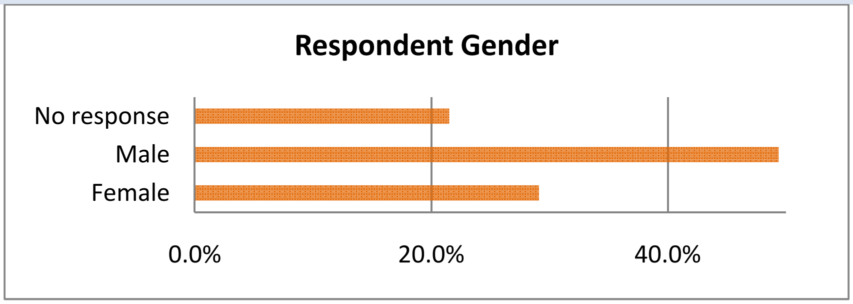
____

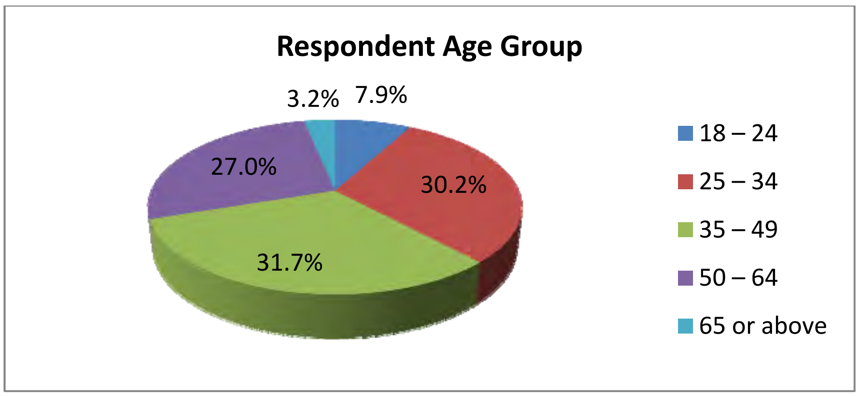
____

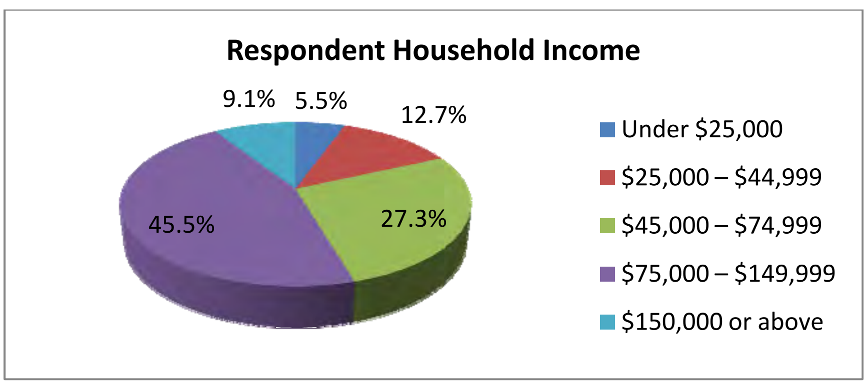
Thank you very much for participating!

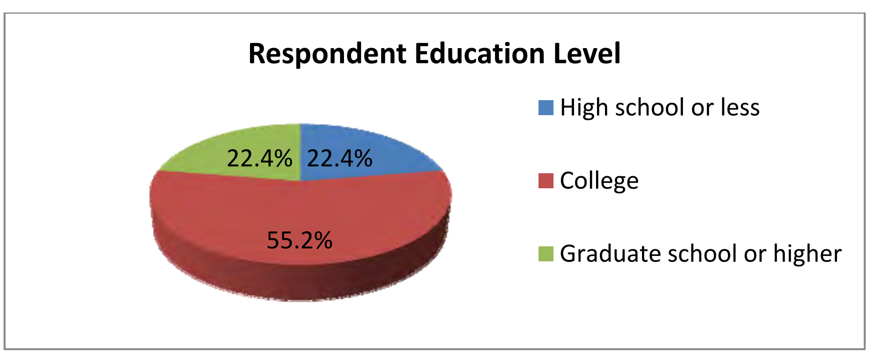
15 APPENDIX III – SURVEY RESULTS

15.1 DEMOGRAPHIC CHARACTERISTICS

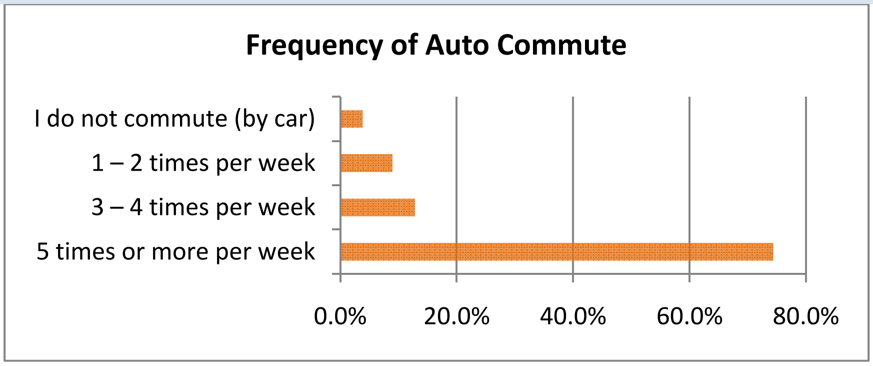


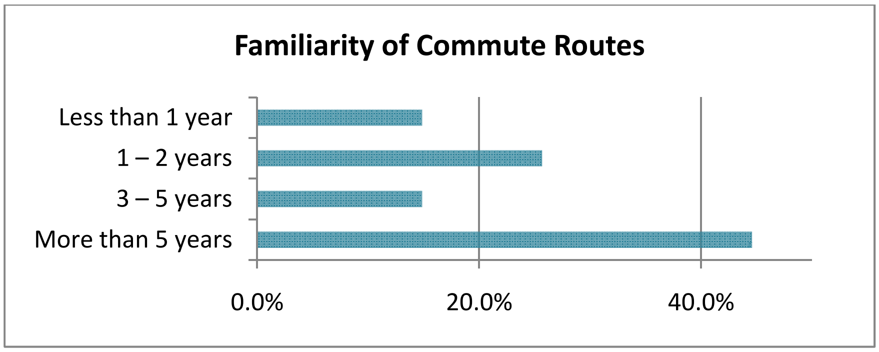


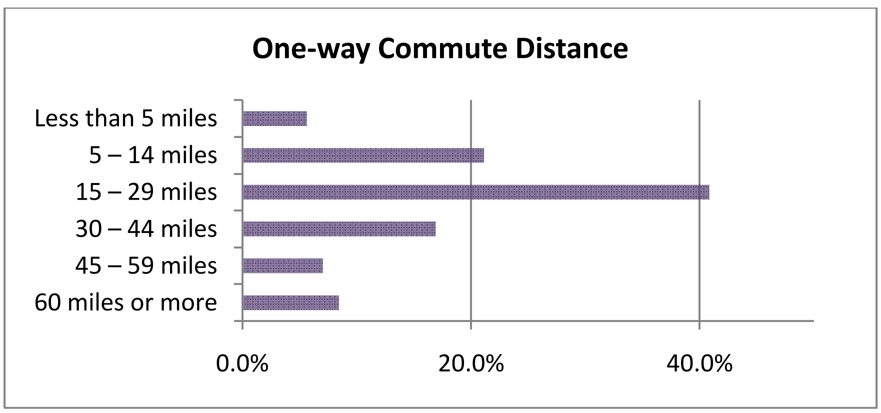


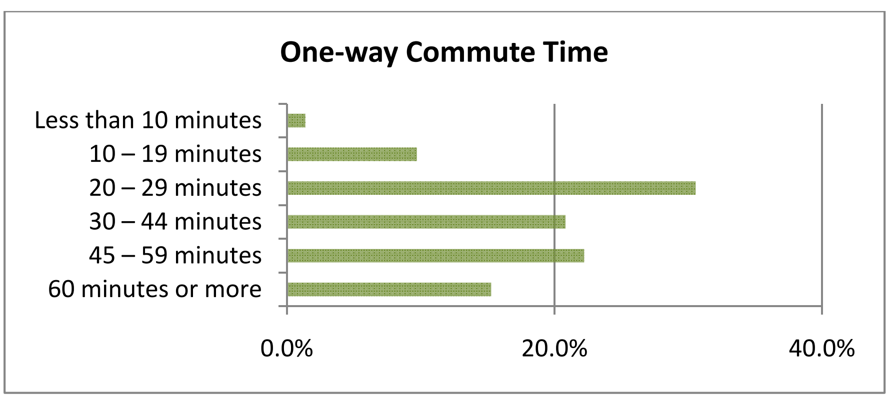


15.2 COMMUTING ATTRIBUTES

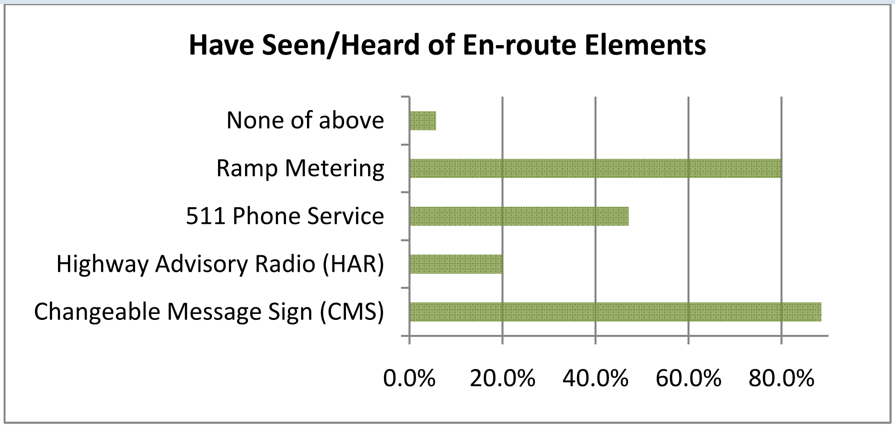


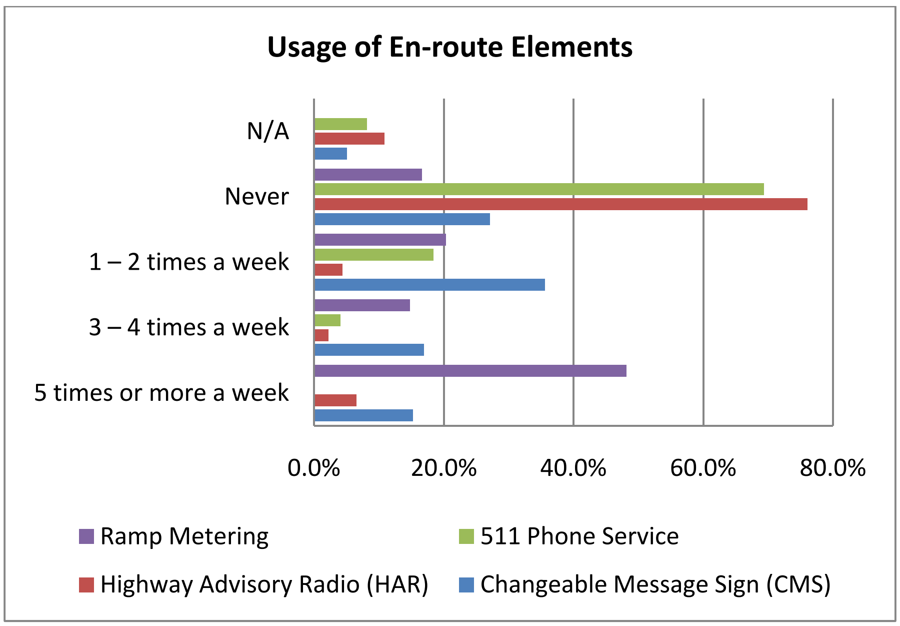


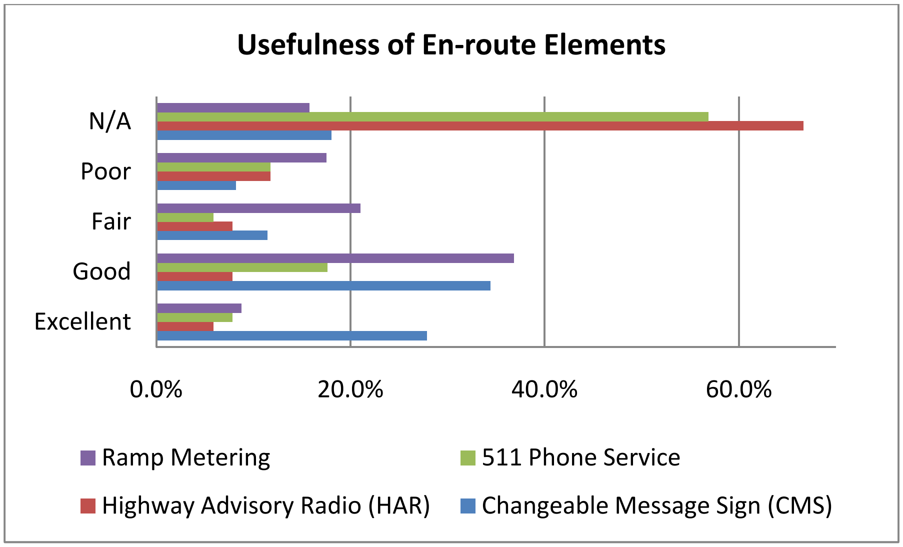


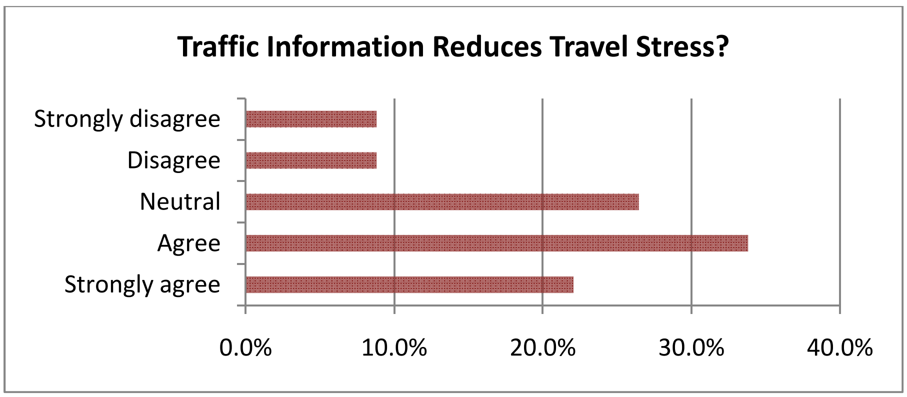


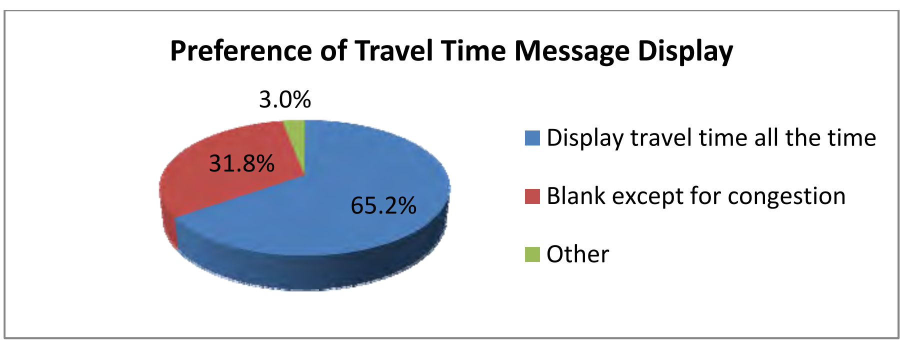
15.3 ABOUT EN-ROUTE INFORMATION AND CONTROL ELEMENTS



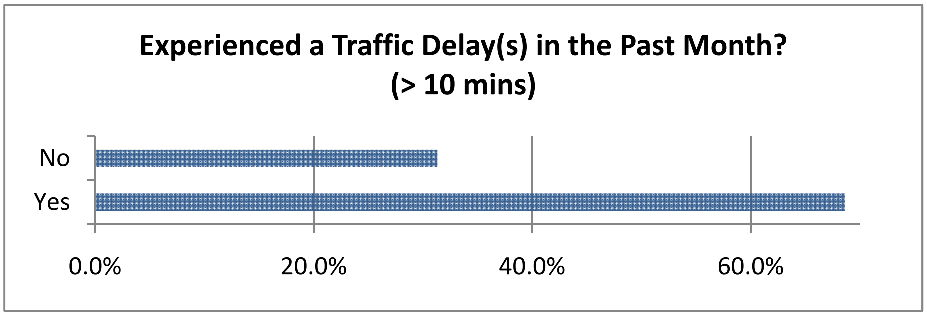


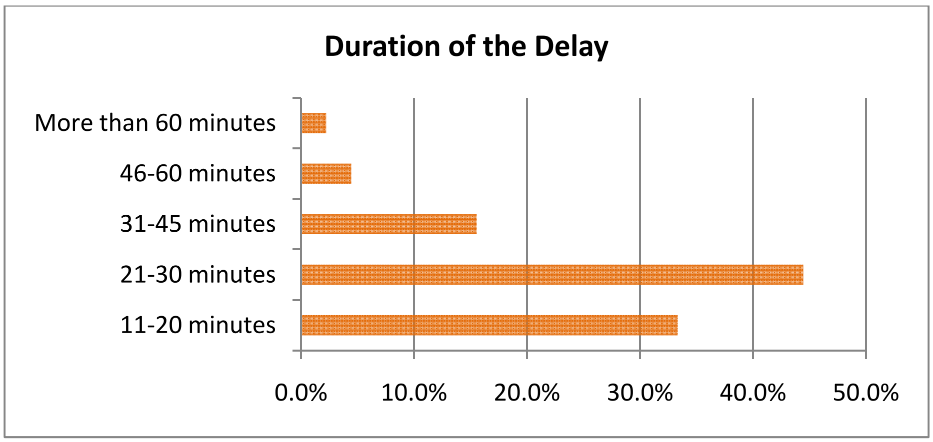

Usefulness of En-route Elements
N/A
Poor
Fair
Good
Excellent
0.0%
20.0%
40.0%
60.0%
Ramp Metering
511 Phone Service
Highway Advisory Radio (HAR)
Changeable Message Sign (CMS)

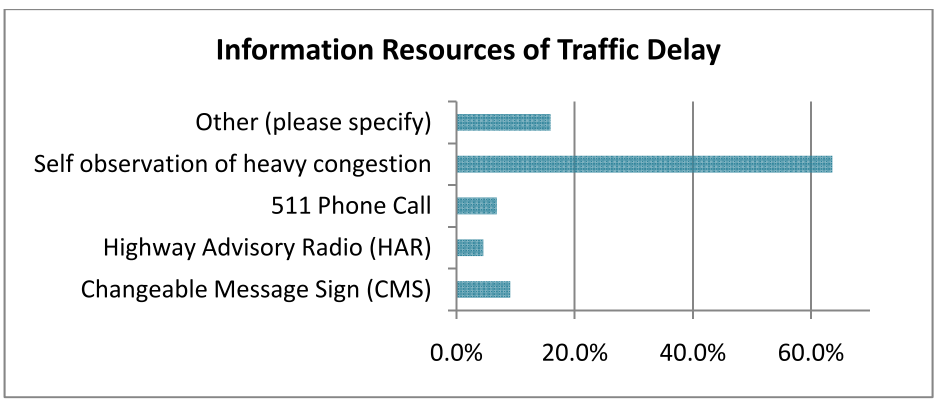

Traffic Information Reduces Travel Stress?
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
0.0%
10.0%
20.0%
30.0%
40.0%

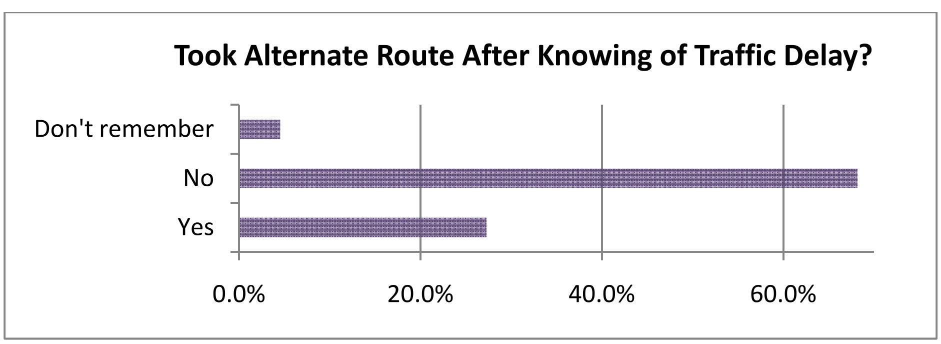

Preference of Travel Time Message Display
3.0%
31.8%
65.2%
Display travel time all the time
Blank except for congestion
Other

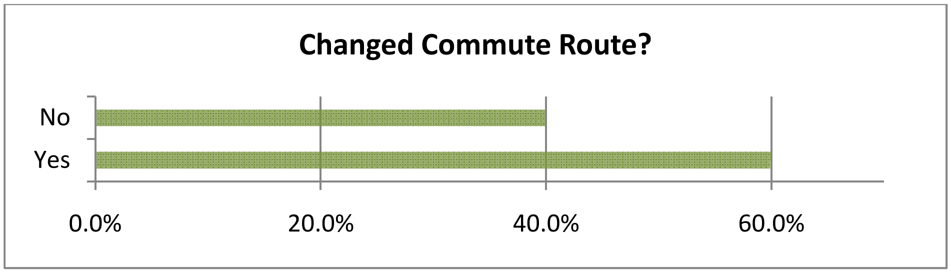
15.4 ABOUT EN-ROUTE TRAFFIC DELAY AND ROUTE CHOICE

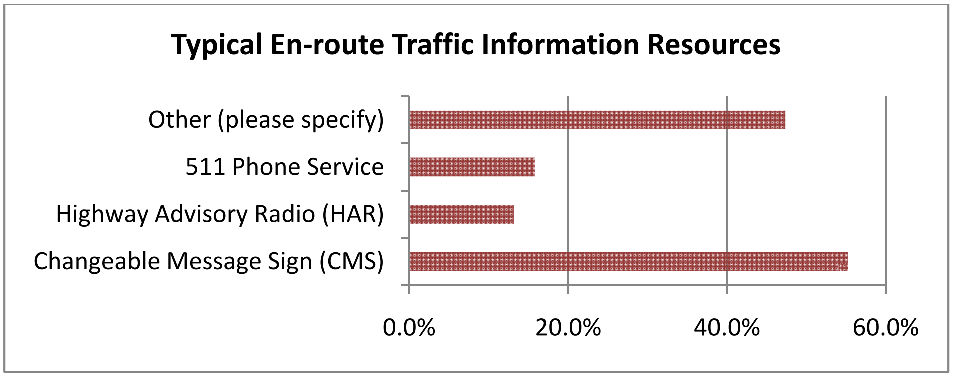


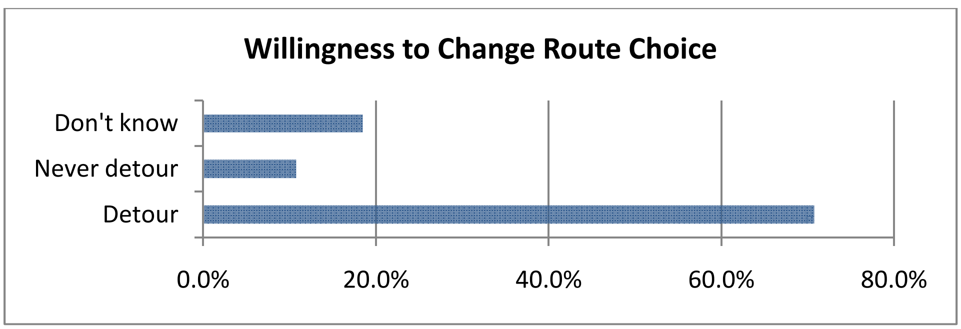


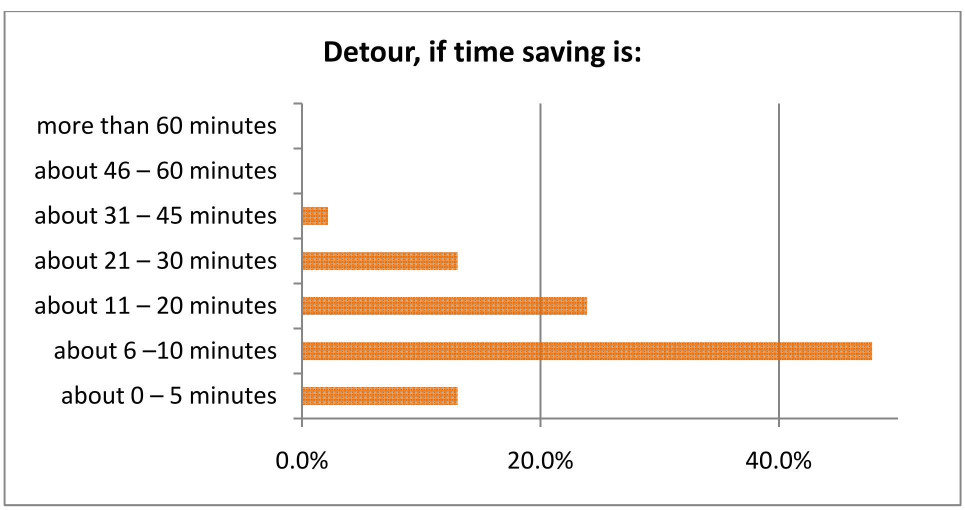




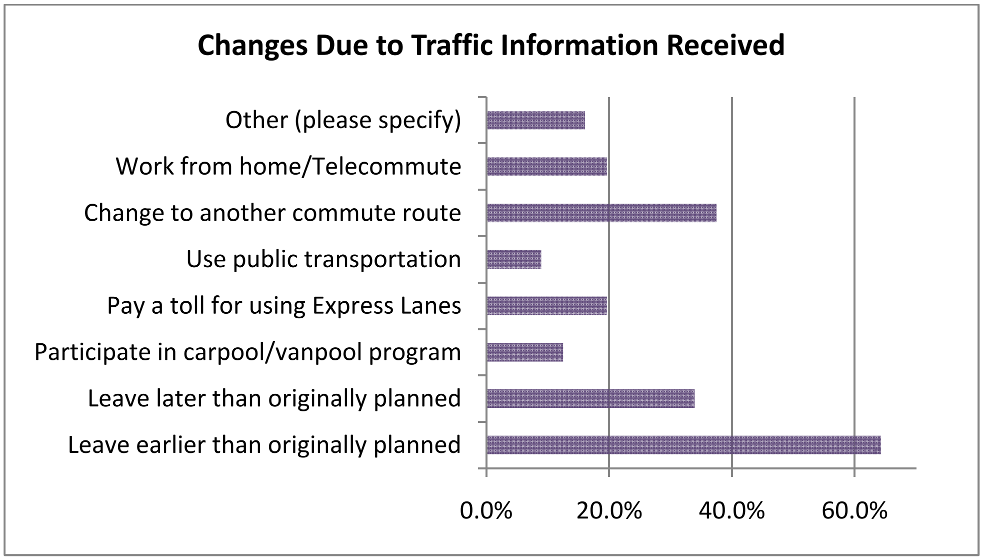

Changed Commute Route?
No
Yes
0.0%
20.0%
40.0%
60.0%

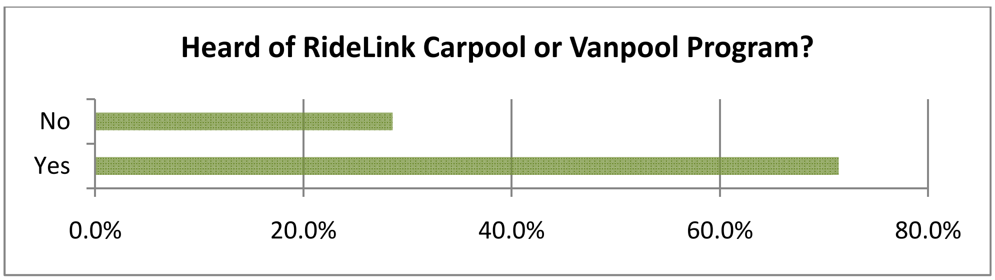

Typical En-route Traffic Information Resources
Other (please specify)
511 Phone Service
Highway Advisory Radio (HAR)
Changeable Message Sign (CMS)
0.0%
20.0%
40.0%
60.0%

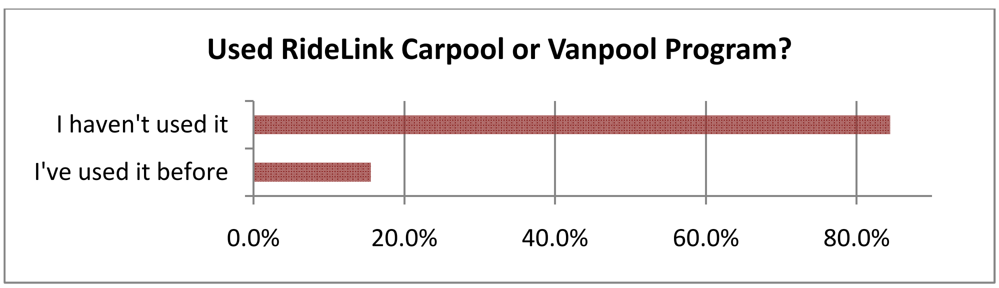

Willingness to Change Route Choice
Don't know
Never detour
Detour
0.0%
20.0%
40.0%
60.0%
80.0%

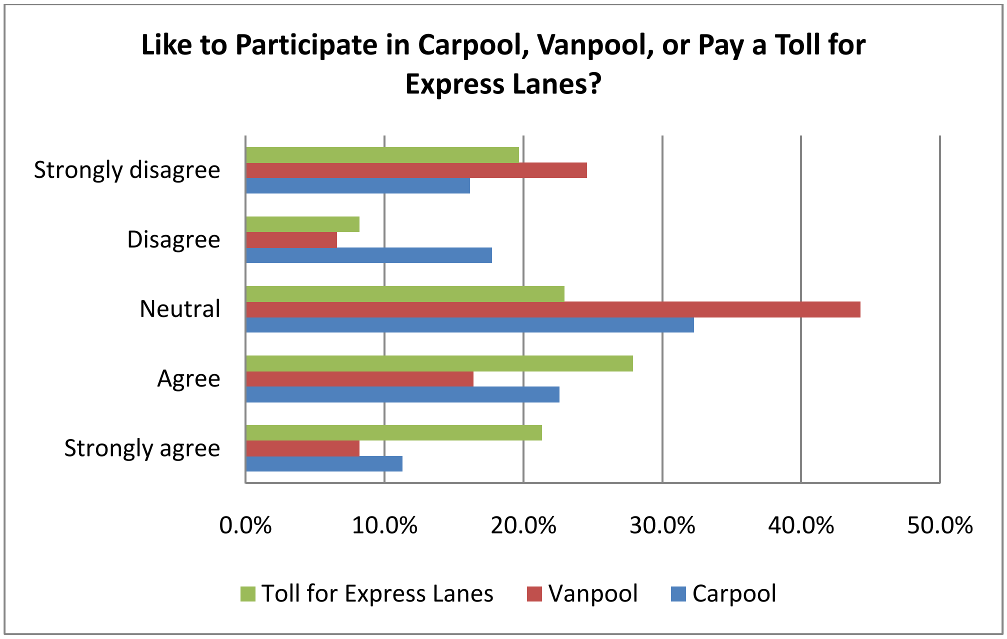

Detour, if time saving is:
more than 60 minutes
about 46 – 60 minutes
about 31 – 45 minutes
about 21 – 30 minutes
about 11 – 20 minutes
about 6 –10 minutes
about 0 – 5 minutes
0.0%
20.0%
40.0%

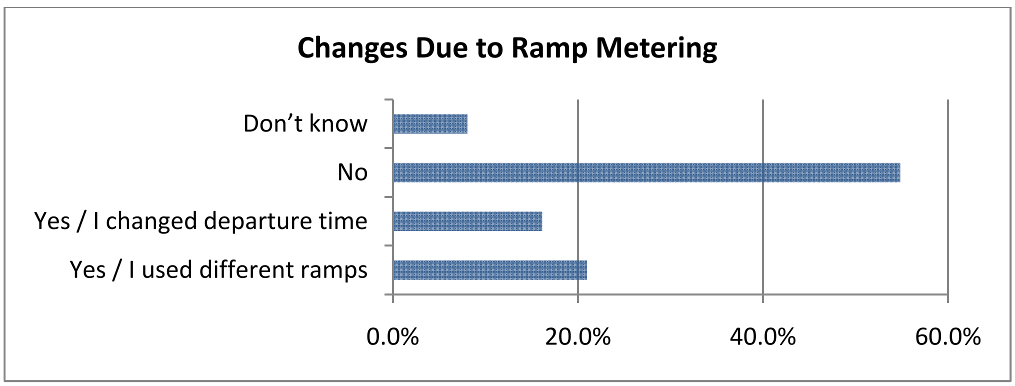
15.5 OTHER COMMUTER TRAVEL CHOICES








Like to Participate in Carpool, Vanpool, or Pay a Toll for Express Lanes?
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
Toll for Express Lanes
Vanpool
Carpool


Changes Due to Ramp Metering
Don't know
No
Yes / I changed departure time
Yes / I used different ramps
0.0%
20.0%
40.0%
60.0%

15.6 WRITE-IN COMMENTS

The metering onto I-80 Eastbound from Sports Arena Blvd needs to be 2 cars per light or quicker!

I would like an option on 511 or configure an email or SMS alert. I would like to be able to select my morning and evening routes, select a time range when I would like to receive alerts, and configure a maximum commute time alert. Another way of saying this is I would like to say Notify me by SMS and email, when the commute time from Sorrento Valley to Coronado is greater than 45 minutes but only send me the alerts starting at 4:30 until 6:30 and update me every 15 minutes with the latest commute time if greater than 45 minutes and the first time the commute time is less than 45 minutes, indicating the traffic has improved.

Would love to see some sort of public service announcements about all the new options on the I15. You need to get the word out...especially to the people commuting from Murrietta and Temecula!!!

Most of the time I take the bus and Coaster to work to completely avoid the congestion. I wish they had one more northbound AM Coaster around 7 AM (from Santa Fe Depot) and another southbound Coaster about 5 PM (from Sorrento Valley)

Hurry up and finish the freeway so i can get home faster!!! LOL

Expand the trolley system and have USEABLE mass transit with boarding times every 5 -10 minutes like other big city transit

There are no good alternative routes when the 15 is backed up. Public transportation takes too long and it's difficult for me to carpool because my hours vary too much. The more valid info I have about traffic congestion the better it is for me to plan. I usually stay late on Fridays to avoid traffic and I go to work later than most people for the same reason.

Charge more to use the toll carpool lanes. $0.50 is almost free. It will never change any ones habits until you hit a pain point of $5.00 a trip.

I drive on the streets most of the time and never and of the signs. By the time I am on the road I figure out what rout to take. Seeing that my commute is two miles. Most signs do no good for me.

I generally check the Caltrans web site before leaving work to check traffic. If traffic is bad, I stay and work until it clear up.

Traffic Meter Ramp Signals could be or intelligent based on freeway vs. on-ramp load as to time of day. The amount of cars let on and how long the light stay red between cars could adjust dependent of freeway load and onramp length. This would eliminate traffic caused by groups entering the freeway in large groups from major city onramps. We could accomplish this with research or computer modeling that feeds back to each onramp signal live. Computers are cheap now days, use them for god sakes!!

Also purchased a Natural Gas fueled car to take advantage of the Diamond Lanes..

I have been commuting on the 15 freeway for 13 years. I can't even begin to calculate the wasted hours I have spent trapped in my car on the 15 - my calculator can't go that high! I was truly excited construction finally began and extremely disappointed on the final outcome. What the heck! Where are the buses? Where is the zipper? AND FOR GOD SAKES WHY WEREN'T MORE ON/OFF RAMPS CONSTRUCTED FOR FASTTRAK? What a waste! The few that were constructed drop off right in the middle of stopped traffic, which only adds to my frustration. This redesign of the 15 freeway is absolutely ridiculous and a huge waste of money.

Traffic in san diego SUCKS and people can't drive with their heads up their butts doing other things like talking on the phone, reading, smoking, putting on makeup, picking their noses, etc.

Beginning about 2 years ago I started using 94 to 163 route due to heavy congestion on 805 Northbound. I Blame the new homes in Otay Mesa. We should not be building any new homes in S.D. county. We are overusing our resources as it is! NO GROWTH/NO EXPANSION!!!!

The traffic travel times displayed on the changeable signs is great! they should be on at all times. ramp signals however wreak havoc on the streets getting to the on-ramps. at times, it can take almost as much time to get onto the freeway as it does to drive the 18 miles on the freeway to get to my destination

Managed lanes should have been used for the (free)way and not for toll lanes. I think traffic would have been alleviated alot better if used in this manner.

I think it is great that carpool and vanpools are offered. I'm very interested in receiving more information about it. Thank you.

There have been quite a few instances when there is some type of construction on the freeway, with no warning signs of arrows until your almost on top of it. I have almost been in so many accidents because of this. Do you not have people out there checking for these potential problems before they occur. If the answer is YES, there not doing there jobs very well. How are suppose to "WATCH THE CONE ZONE" when there isn't enough warning....

The Genesee to I-5 interchange is inefficient. Also I'm not sure if the demand is there, however I would love for there to be express bus/train commuting routes to UTC like there are to downtown possibly from the new sabre springs transit center to UTC?).

Love the new fast trac lanes. I commute to OC on the weekends. It would be great to have a better way to get from San Diego to OC.

16 APPENDIX IV – SPEED CONTOUR MAP FOR OTHER SCENARIOS

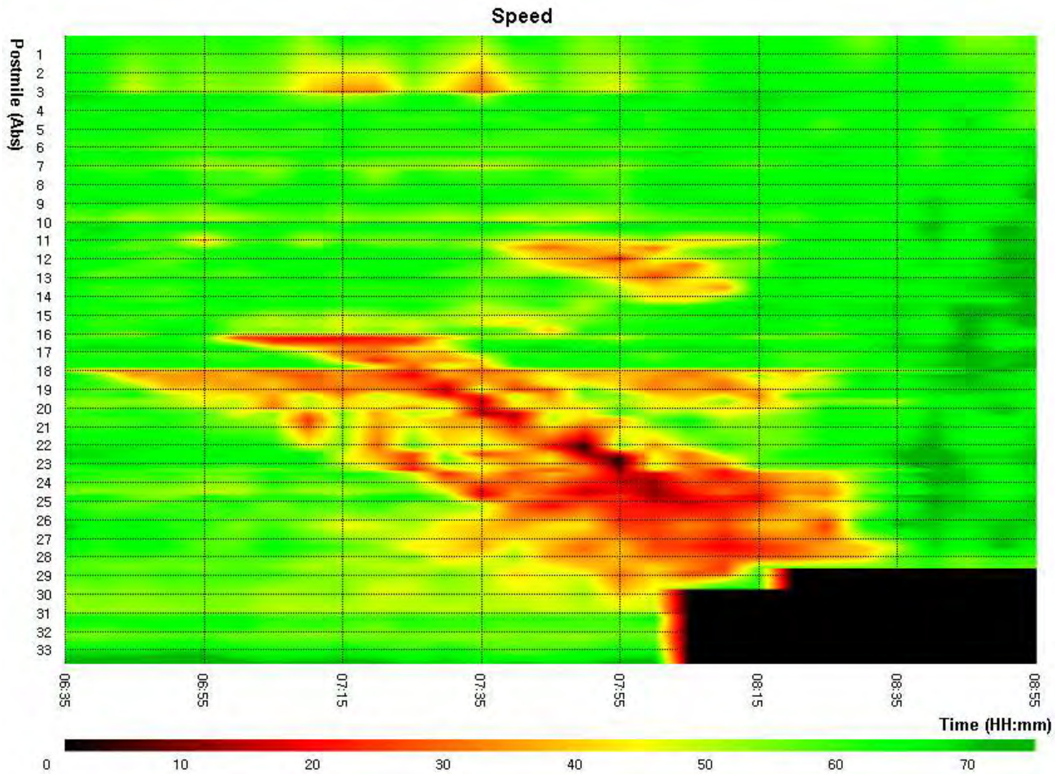


Figure 16-1: Speed contour for I-880: Incident and 10% diversion

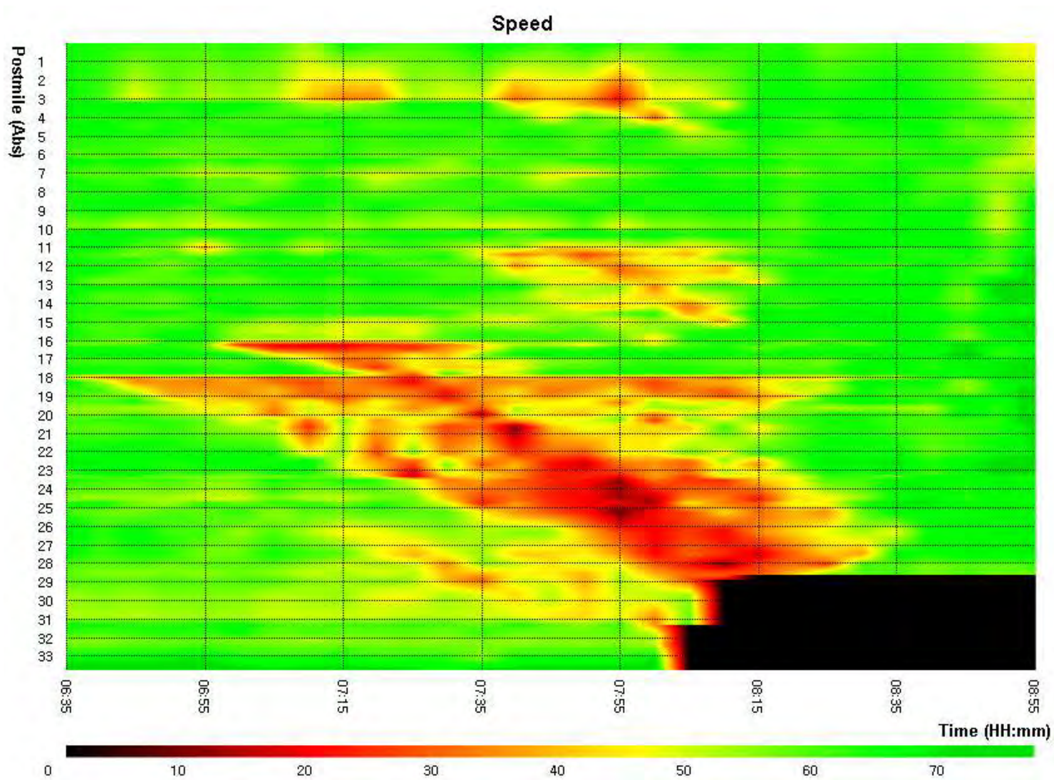


Figure 16-2: Speed contour for I-880: Incident and 20% diversion

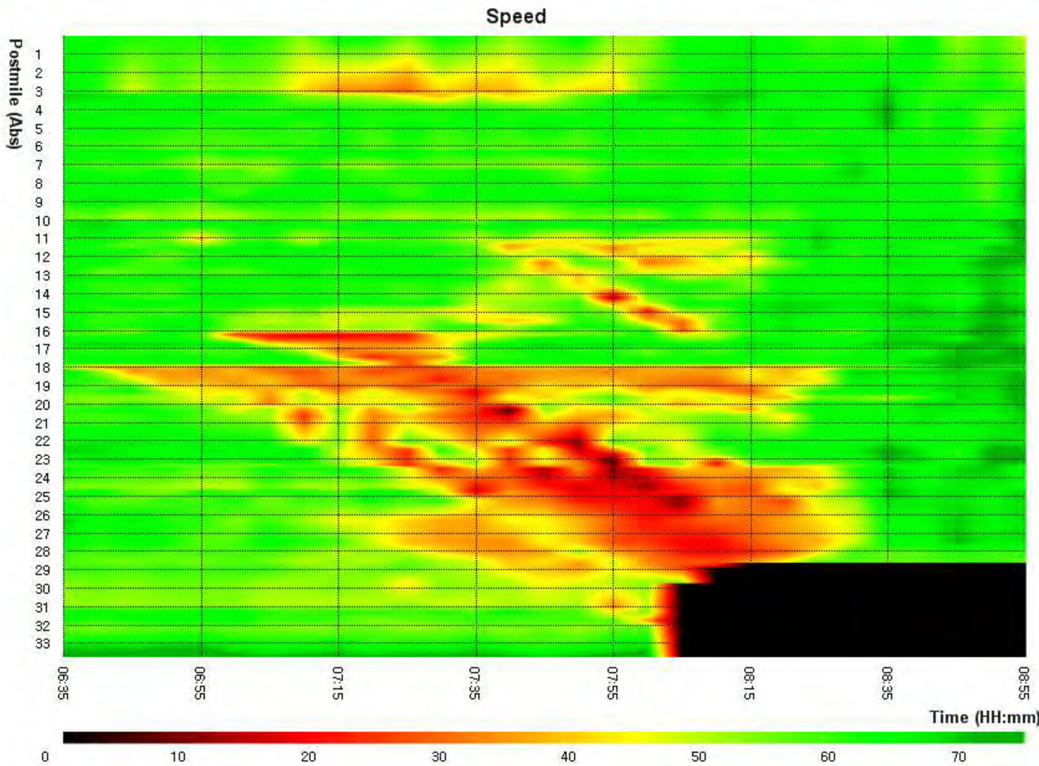


Figure 16-3: Speed contour for I-880: Incident and 30% diversion

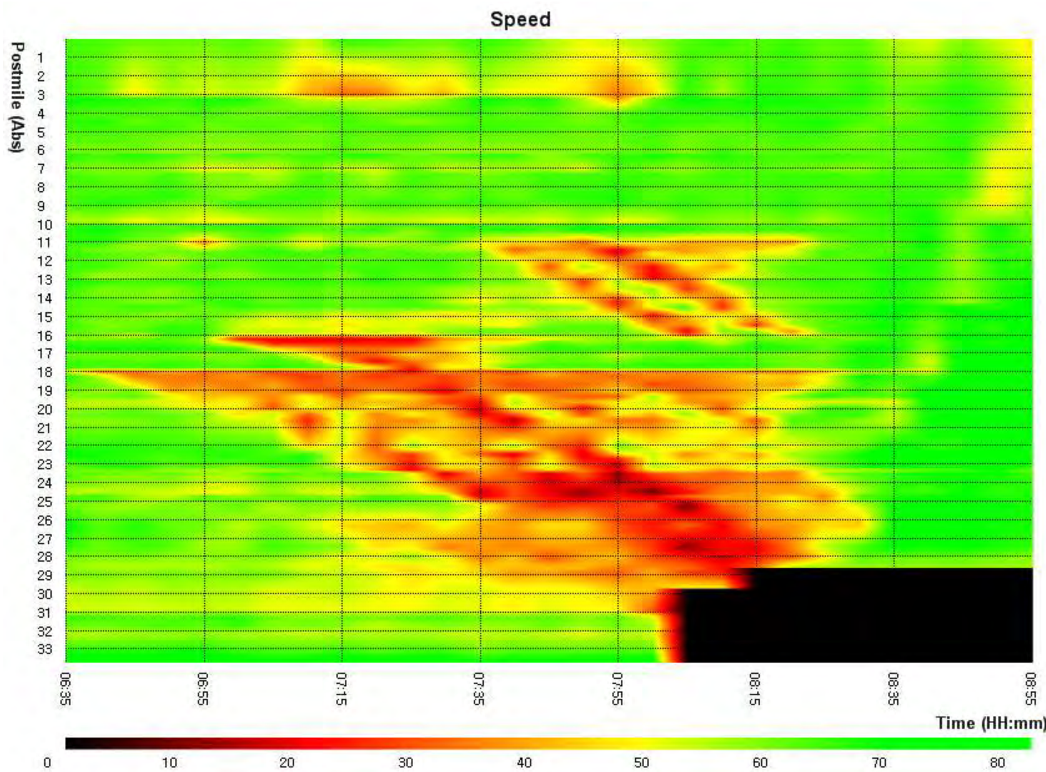


Figure 16-4: Speed Contour for I-880: Incident and 40% diversion

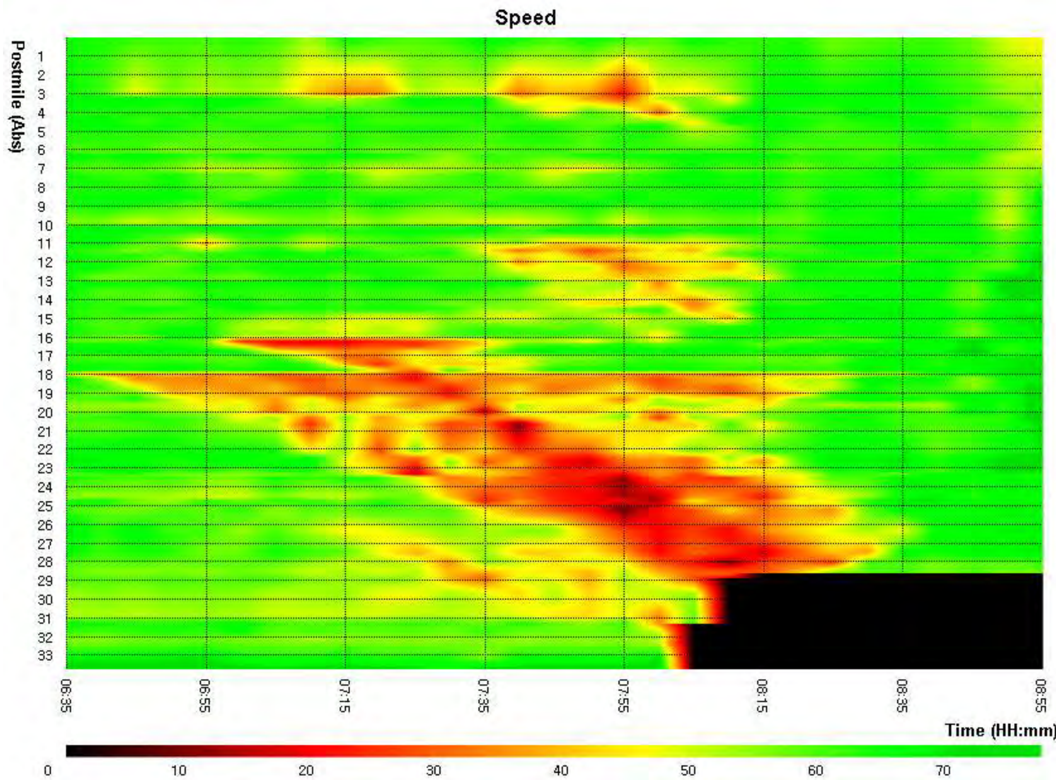


Figure 16-5: Speed contour for I-880: incident and 20% diversion andfamiliarity 5

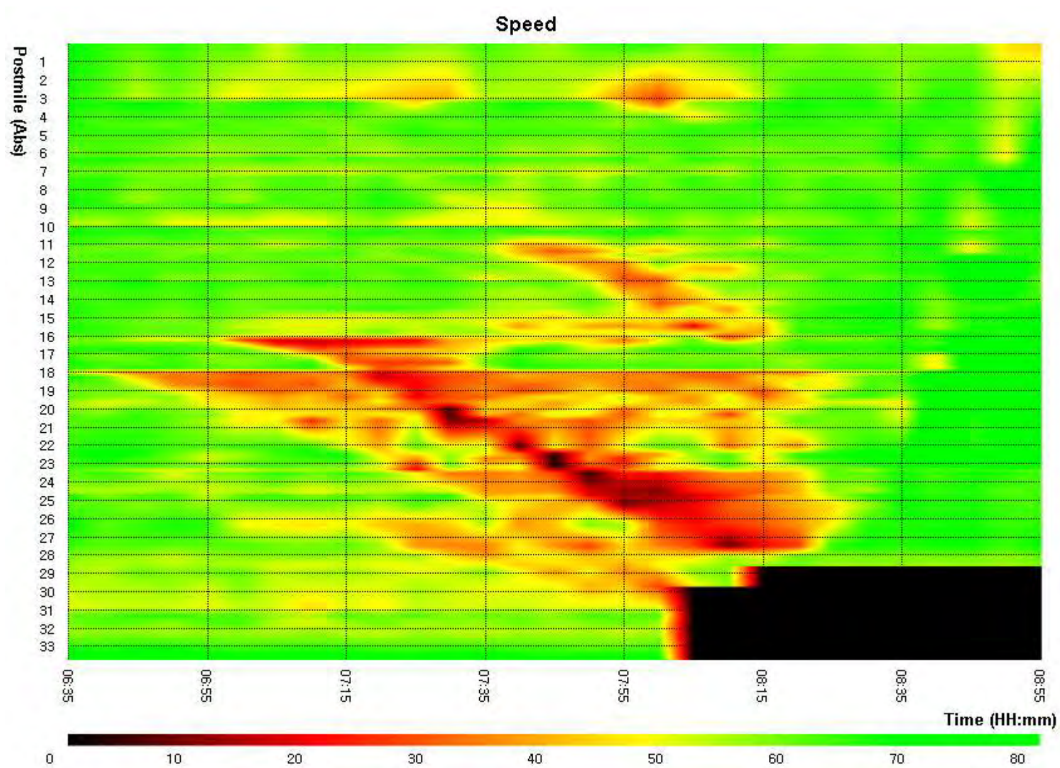


Figure 16-6: Speed contour for I-880: Incident and 20% diversion andfamiliarity 10

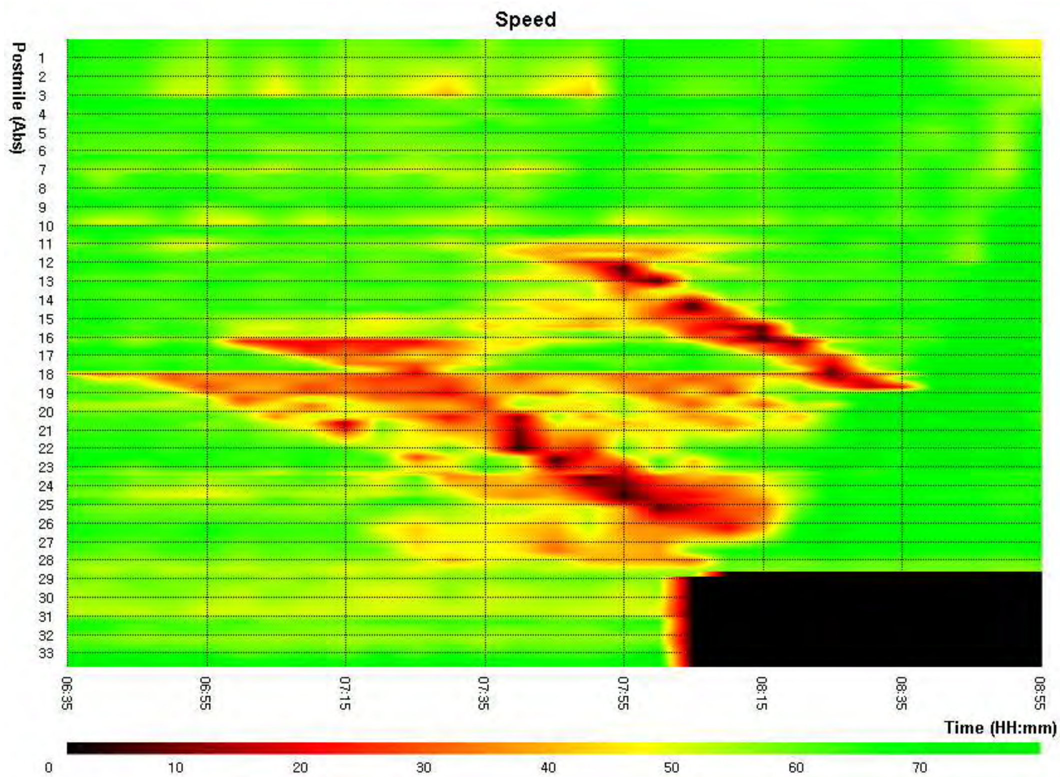


Figure 16-7: Speed contour for I-880: Incident and 20% diversion andfamiliarity 15

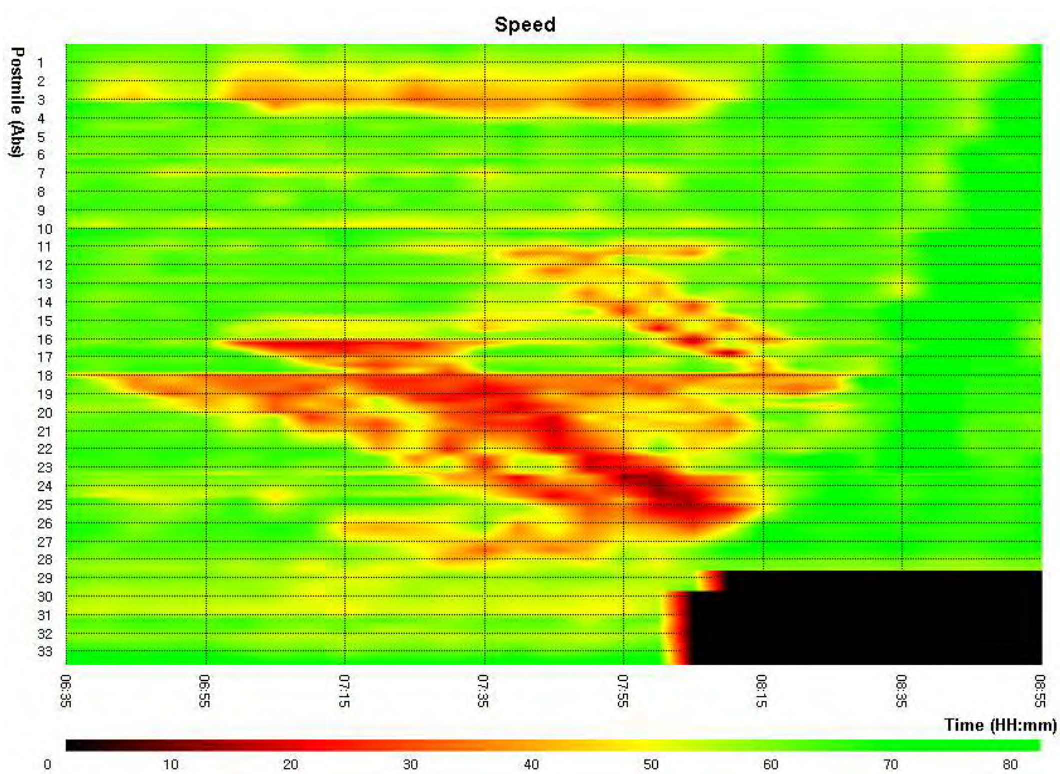


Figure 16-8: Speed contour for I-880: incident and 20% diversion andfamiliarity 20

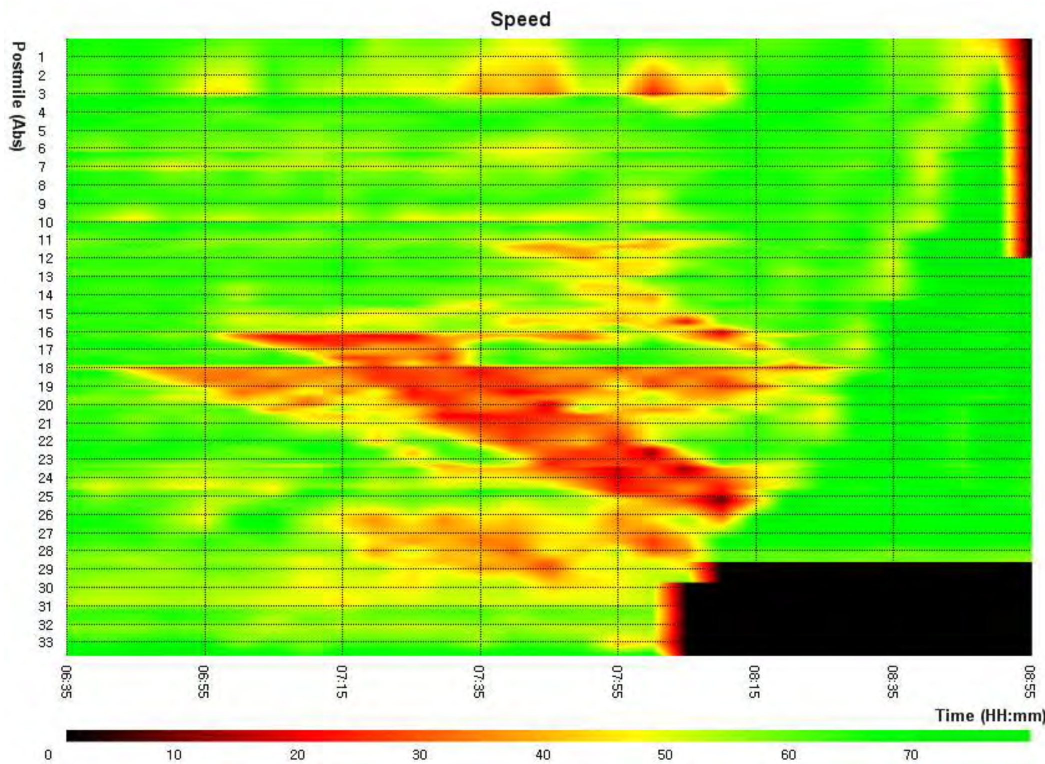


Figure 16-9: Speed contour for I-880: Incident and 20% diversion andfamiliarity 25

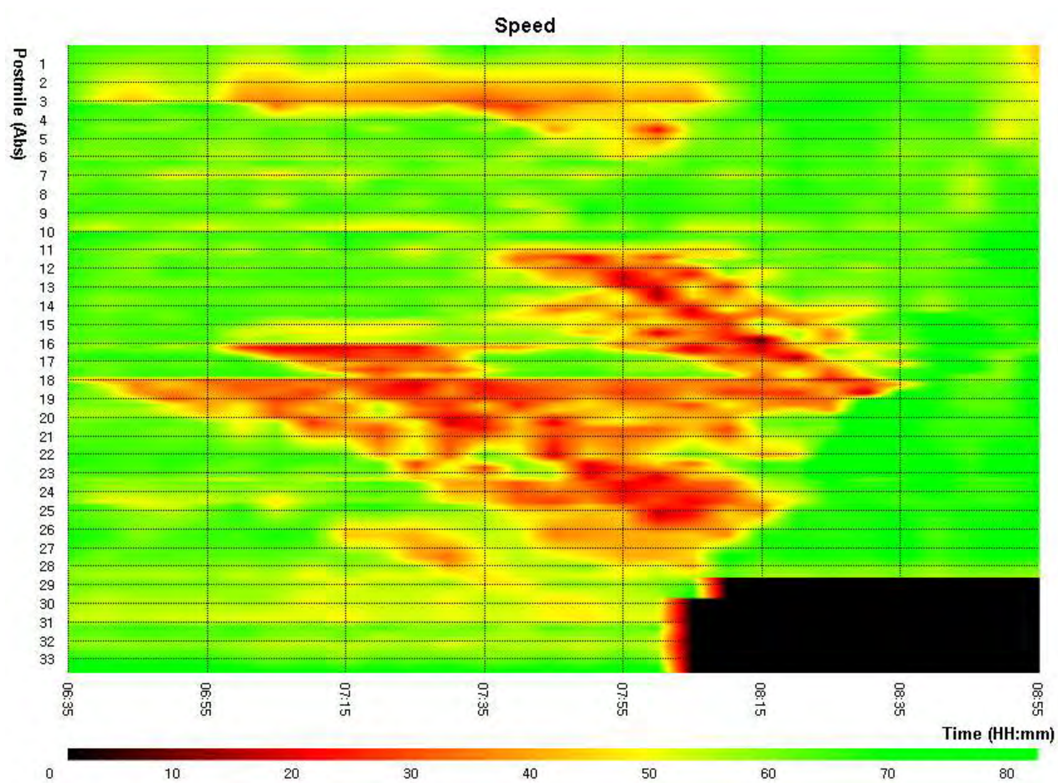


Figure 16-10: Speed contour for I-880: Incident and 30% diversion andfamiliarity 20

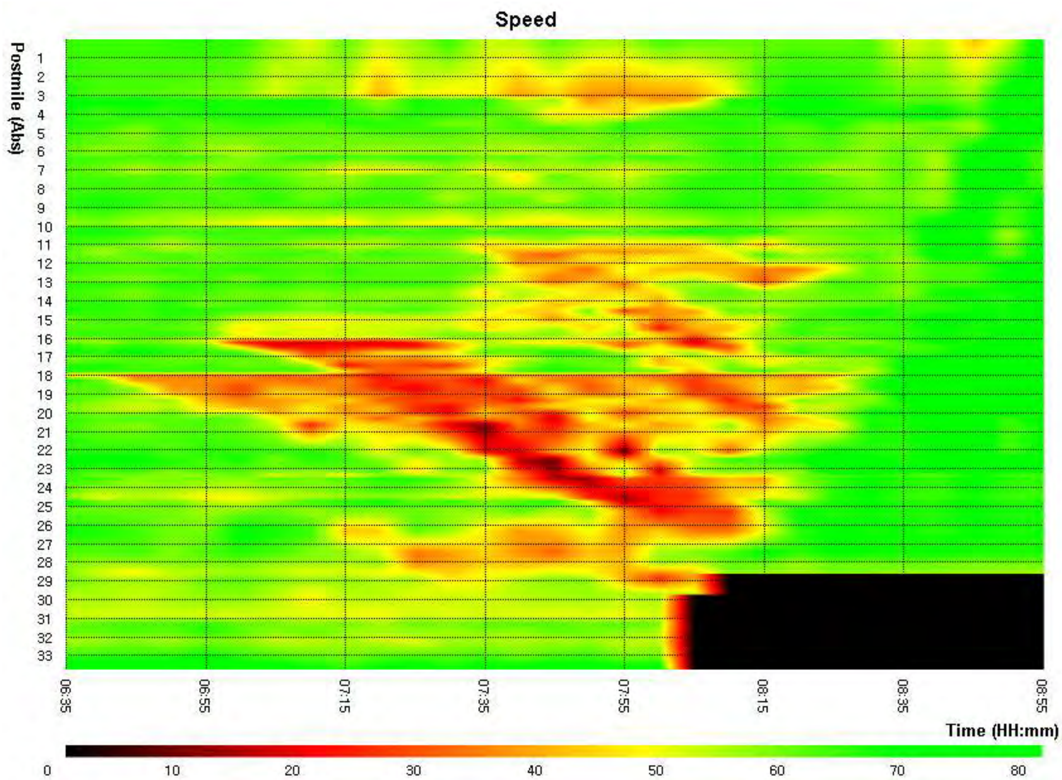


Figure 16-11: Speed Contour for I-880: Incident andno diversion andfamiliarity 20

---

i http://www.itsdeployment.its.dot.gov/FactSheet.asp

ii Wei, Wen-Bin. Probe Vehicle Surveillance. ITS Decision Report, PATH, University of California-Berkeley, Institute of Transportation Studies, Berkeley, California, 1998.

iii John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

iv http://ops.fhwa.dot.gov/travelinfo/resources/cms_rept/travtime.htm

v http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

vi http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

vii http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

viii http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

[ix] http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/CMS%20Operation%20and%20Messaging%20Handbook-Final%20Draft.pdf

[x] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm

[xi] http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/White%20Paper%20Nov%2027%2002.doc

Page 52, *Use of Graphics and Symbols in Messages*

[xii] Huchingson et al. (1978a) - http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/White%20Paper%20Nov%2027%2002.doc

Page 52, *Use of Graphics and Symbols in Messages*

[xiii] http://mutcd.fhwa.dot.gov/

[xiv] http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/White%20Paper%20Nov%2027%2002.doc

Page 52, *Use of Graphics and Symbols in Messages*

[xv] http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/White%20Paper%20Nov%2027%2002.doc

Page 52, *Use of Graphics and Symbols in Messages*

[xvi] Dudek, C.L. Changeable Message Signs—Synthesis of Highway Practice 61. National Cooperative Highway Research Program, 1979.

[xvii] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xviii] http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

[xix] http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

[xx] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxi] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxii] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxiii] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxiv] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxv] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxvi] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxvii] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxviii] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxix] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxx] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxxi] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxxii] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxxiii] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxxiv] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxxv] http://www.ops.fhwa.dot.gov/travelinfo/resources/cms_rept/cmspractices.htm#_ftn3

[xxxvi] ITS Benefits: Continuing Successes and Operational Test Results. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., October 1997.

[xxxvii] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[xxxviii] http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=FM

[xxxix] http://www.itsbenefits.its.dot.gov/its/benecost.nsf/Lesson?OpenForm&4DB1D454425571DD852570A6004962B8^Home,http://www.ops.fhwa.dot.gov/TravelInfo/resources/cms_rept/cmspractices.htm#_Toc73422552

[xl] Operational Guidelines for the Use of Changeable Message Signs. http://www.ncdot.org/doh/preconstruct/traffic/congestion/docs/cmsopera.pdf. North Carolina Department of Transportation, 1999.

[xli] Changeable Message Signs Operation and Messaging Handbook, http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/CMS%20Operation%20and%20Messaging%20Handbook-Final%20Draft.pdf. 2004.

[xlii] *Manual on Uniform Traffic Control Devices*. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., 2003.

[xliii] http://www.fhwa.dot.gov/legsres/directives/policy/pame.htm. January 19, 2001.

http://mutcd.fhwa.dot.gov/res-memorandum_clickit.htm. March 6, 2002.

http://www.fhwa.dot.gov/legsregs/directives/policy/ambermemo.htm. August 16, 2002.

http://www.fhwa.dot.gov/legsregs/directives/policy/securmemo.htm. March 21, 2003.

http://www.i95coalition.org/PDF/Calendar/travel time-memo-ver3.pdf. July 16, 2004.

[xliv] Dudek, C.L. *Variable Message Sign Operations Manual*. Report FHWA-NJ-2001-10, New Jersey Department of Transportation, December 2001.

[xlv] Operational Guidelines for the Use of Changeable Message Signs. http://www.ncdot.org/doh/preconstruct/traffic/congestion/docs/cmsopera.pdf. North Carolina Department of Transportation, 1999.

[xlvi] Dudek, C.L. and R.D. Huchingson. *Manual on Real-Time Motorist Information Displays.* Report FHWA-IP-86-16. FHWA, U.S. Department of Transportation, August 1986.

Dudek, C.L. *Guidelines on the Use of Changeable Message Signs*. Report FHWA-TS-90-043. FHWA, U.S. Department of Transportation, July 1991.

Dudek, C.L. *Changeable Message Signs*. National Cooperative Research Highway Program, Synthesis of Highway Practice 237, TRB, National Research Council, 1997.

Dudek, C.L. *Variable Message Sign Operations Manual*. Report FHWA-NJ-2001-10, New Jersey Department of Transportation, December 2001.

[xlvii] CCIT. http://www.calccit.org/itsdecision/serv_and_tech/Traveler_information/Enroute/har_summary.html

[xlviii] CCIT. http://www.calccit.org/itsdecision/serv_and_tech/Traveler_information/Enroute/har_summary.html

[xlix] CCIT. http://www.calccit.org/itsdecision/serv_and_tech/Traveler_information/Enroute/har_summary.html

[l] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[li] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[lii] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[liii] http://www.itsoverview.its.dot.gov/Options.asp?System=FM&SubSystem=ID&Tech=HAR

[liv] http://www.itsdeployment.its.dot.gov/Results.asp?ID=302

[lv] CCIT. http://www.calccit.org/itsdecision/serv_and_tech/list.html

[lvi] CCIT. http://www.calccit.org/itsdecision/serv_and_tech/list.html

[lvii] CCIT. http://www.calccit.org/itsdecision/serv_and_tech/list.html

[lviii] http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/14247.htm

[lix] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[lx] http://www.itsdocs.fhwa.dot.gov//JPODOCS/REPTS_TE//13955.html, http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/9C9B6CD504DCC72985256FA3006B3831?OpenDocument&Query=Home

[lxi] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[lxii] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[lxiii] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[lxiv] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter13_02.htm

[lxv] Systems analysis and design guidelines for highway advisory radio. FHWA/RD-80/176. 1981.

[lxvi] Virginia Department of Transportation HAR Operational Guidelines. http://ntl.bts.gov/lib/6000/6200/6257/Har.pdf. Virginia Transportation Research Council. 1995.

Highway Advisory Radio Operational Guidelines. New York State DOT. 2003.

Design guidelines for including intelligent transportation systems on projects. http://www.cotrip.org/its/ITS%20Guidelines%20Web%20New%20Format%202-05/ITS%20GUIDELINES%20Fund%201-05.doc. Colorado Department of Transportation, ITS Branch. 2005.

[lxvii] Managing Travel for Planned Special Events / Chapter 6. Traffic Management Plan. http://ops.fhwa.dot.gov/program_areas/sp-events-mgmt/handbook/chapter6_07.htm. FHWA. 2003.

[lxviii] Virginia Department of Transportation HAR Operational Guidelines. http://ntl.bts.gov/lib/6000/6200/6257/Har.pdf. Virginia Transportation Research Council. 1995.

[lxix] *511 general information*. http://www.fhwa.dot.gov/trafficinfo/511.htm.

[lxx] http://www.deploy511.org/index.htm

[lxxi] http://www.deploy511.org/index.htm

[lxxii] http://www.deploy511.org/images/511%20Deployment%20Status%20as%20of%20Sept%204%202007.jpg

[lxxiii] Source: http://www.itsdeployment.its.dot.gov/Trends2006.asp?comp=RMTI

[lxxiv] http://www.deploy511.org/docs/Value_of_Deploying_511_slides.pdf

[lxxv] http://www.deploy511.org/docs/Value_of_Deploying_511_slides.pdf

[lxxvi] http://www.its.dot.gov/jpodocs/repts_te/14319.htm

[lxxvii] http://www.its.dot.gov/jpodocs/repts_te/14319.htm

[lxxviii] 511 Deployment Coalition, *Implementation and Operational Guidelines for 511 Services, Version 2.0,* Washington, DC: September 2003. www.deploy511.org/guidelinesv2_intro.htm

[lxxix] http://www.its.dot.gov/jpodocs/repts_te/14319.htm

[lxxx] Federal Highway Administration, *Intelligent Transportation Systems in Work Zones, A Case Study: Work Zone Traffic and Incident Management System*, *Keeping Traffic Moving During Reconstruction of the Big I, a Major*

Interstate-Interstate Interchange in Albuquerque, Washington, DC: January 2004. www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/13941.html

[lxxxi] Federal Highway Administration, *Final Evaluation Report for the Greater Yellowstone Regional Traveler and Weather Information System (GYRTWIS)*, Washington, DC: December 2003. www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/13958.html

[lxxxii] http://www.its.dot.gov/jpodocs/repts_te/14319.htm

[lxxxiii] Federal Highway Administration, *Metropolitan Model Deployment Initiative – Seattle Evaluation Report*, Washington, DC: May 2000. www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/13071.pdf

[lxxxiv] http://www.its.dot.gov/jpodocs/repts_te/14319.htm

[lxxxv] Federal Highway Administration, *An Evaluation of Acadia National Park ITS Field Operational Test: Final Report*, Washington, DC: June 2003. www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/13834.html

[lxxxvi] http://www.its.dot.gov/jpodocs/repts_te/14319.htm

[lxxxvii] Federal Highway Administration, *Model Deployment of a Regional, Multi-Modal 511 Traveler Information System — Final Report*, Washington, DC: August 2005. www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/14248.htm

[lxxxviii] http://www.its.dot.gov/jpodocs/repts_te/14319.htm

[lxxxix] Federal Highway Administration, *511 Case Studies: San Francisco Bay Area Metropolitan Transportation Commission*, Washington, DC: April 2001. www.its.dot.gov/511/Travinfo.htm

[xc] http://www.deploy511.org/usage.htm

[xci] http://www.deploy511.org/usage.htm

[xcii] http://www.deploy511.org/docs/511-deployevalstatoct2002.xls

[xciii] http://www.deploy511.org/usage.htm

[xciv] http://www.deploy511.org/usage.htm

[xcv] http://www.deploy511.org/usage.htm

[xcvi] http://www.deploy511.org/usage.htm

[xcvii] http://www.deploy511.org/usage.htm

[xcviii] http://www.calccit.org/itsdecision/serv_and_tech/Ramp_metering/ramp_metering_summary.html

[xcix] http://www.calccit.org/itsdecision/serv_and_tech/Ramp_metering/ramp_metering_summary.html

[c] http://www.calccit.org/itsdecision/serv_and_tech/Ramp_metering/ramp_metering_summary.html

[ci] http://www.calccit.org/itsdecision/serv_and_tech/Telecommunications/diagrams/Ramp%20Meters/Ramp%20Meters.htm

---

[cii] http://www.dot.ca.gov/dist11/operations/trfsys.htm

[ciii] http://www.calccit.org/itsdecision/serv_and_tech/Ramp_metering/ramp_metering_summary.html

[civ] http://www.dot.ca.gov/dist11/operations/trfsys.htm

[cv] http://www.dot.ca.gov/dist11/operations/trfsys.htm

[cvi] http://www.dot.ca.gov/dist11/operations/trfsys.htm

[cvii] Ramp Management and Control handbook. http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/default.htm. FHWA. 2006.

[cviii] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/toc.htm. 2003.

[cix] Ramp meter design manual. http://www.dot.ca.gov/hq/traffops/systemops/ramp_meter/RMDM.pdf. California Department of Transportation. 2000.

[cx] Design guidelines for including intelligent transportation systems on projects. http://www.cotrip.org/its/ITS%20Guidelines%20Web%20New%20Format%202-05/ITS%20GUIDELINES%20Fund%201-05.doc. Colorado Department of Transportation, ITS Branch. 2005.

[cxi] Ramp Management and Control handbook. http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/default.htm. FHWA. 2006. (Chapter 9: Ramp Performance Monitoring, Evaluation and Reporting)

[cxii] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[cxiii] Dudek, C.L. *Changeable Message Signs—Synthesis of Highway Practice 61*. National Cooperative Highway Research Program, 1979.

[cxiv] Peeta S, Zhang P, Zhou W. Behavior-based analysis of freeway car-truck interactions and related mitigation strategies. Transportation Research Part B 2005;39(5):417-451.

[cxv] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[cxvi] Golob TF, Regan AC. The perceived usefulness of different source of traffic information to trucking operations. Transportation Research Part E 2002;38(2):97-116.

Golob TF, Regan AC. Trucking industry adoption of information technology: a multivariate discrete choice model. Transportation Research Part C: Emerging Technologies 2002;10(3):205-228.

Golob TF, Regan AC. Trucking industry preferences for traveler information for drivers using wireless Internet-enabled devices. Transportation Research Part C: Emerging Technologies 2005;13(3):235-250.

[cxvii] Konduri S, Labi S, Sinha K. Incident occurrence models for freeway incident management. Transportation Research Record 2003;1856:35-44.

[cxviii] Khattak AJ, Schofer JL, Wang M-H. A Simple Time Sequential Procedure for Predicting Freeway Incident Duration. IVHS Journal 1995;2(2):113-138.

[cxix] Weisbrod G, Vary D, Treyz G. Economic Implication of Congestion. Washington, DC: Transportation Research Board; 2001. Report No.: NCHRP Report #463.

[cxx] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[cxxi] Ramp Management and Control handbook. http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/default.htm. FHWA. 2006. (Chapter 9: Ramp Performance Monitoring, Evaluation and Reporting)

[cxxii] Ramp Management and Control handbook. http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/default.htm. FHWA. 2006. (Chapter 9: Ramp Performance Monitoring, Evaluation and Reporting)

[cxxiii] Ramp Management and Control handbook. http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/default.htm. FHWA. 2006. (Chapter 9: Ramp Performance Monitoring, Evaluation and Reporting)

[cxxiv] Chapter 4 – Performance Monitoring and Evaluation. Freeway Management and Operations Handbook. FHWA. http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter4_01.htm#4-1. 2003.

[cxxv] *Freeway Management and Operations Handbook.* Publication FHWAOP-04-003. FHWA, U.S. Department of Transportation. September 2003. Available: http://ops.fhwa.dot.gov/freewaymgmt/freeway_mgmt_handbook/index.htm.

[cxxvi] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.

[cxxvii] ITS Performance and Benefit Study. National ITS Architecture. http://www.iteris.com/itsarch/documents/perfben/perfben.pdf. 1996.

[cxxviii] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006. Page 15.

[cxxix] Travel Time Reliability: Making It There On Time, All The Time. FHWA. http://ops.fhwa.dot.gov/publications/tt_reliability/brochure/index.htm. 2006.

[cxxx] *National State of Congestion, Appendix D*. Cambridge Systematics, Inc. May 2004.

[cxxxi] Adler JL, Blue VJ. Toward the Design of Intelligent Traveler Information Systems. Transportation Research Part C: Emerging Technologies 1998;6(3):157-172.

[cxxxii] http://www.its.ucdavis.edu/publications/2004/UCD-ITS-RR-96-03(02)_rev1.pdf

[cxxxiii] Haselkorn M, Spyridakis J, Conquest L, Barfield W. Surveying commuter behavior as a basis for designing motorist information systems. In: The First Vehicle Navigation and Information Systems Conference, IEEE; 1989; Toronto, Canada; 1989. p. 93-100.

Khattak AJ, Schofer JL, Koppelman FS. Factors Influencing Commuters' En Route Diversion Behavior in Response to Delay. Transportation Research Record 1991;1318:125-136.

Smiley A. Behavioral Adaptation, Safety, and Intelligent Transportation Systems. Transportation Research Record 2000;1724:47-51.

[cxxxiv] Smiley A. Behavioral Adaptation, Safety, and Intelligent Transportation Systems. Transportation Research Record 2000;1724:47-51.

[cxxxv] J.L. Schofer, A. Khattak and F.S. Koppelman, Behavioral issues in the design and evaluation of advanced traveler information systems. *Transportation Research* 1C (1993), pp. 107–117.

Asad J. Khattak, Felipe Targa, Youngbin Yim. Advanced Traveler Information Systems: Relationship to Traveler Behavior, Chapter 12 in *Assessing the Costs and Benefits of Intelligent Transportation Systems*, Kluwer Academic Publishers, Edited by D. Gillen and D. Levinson, 2004, pp. 218-240.

[cxxxvi] Asad J. Khattak, Felipe Targa, Youngbin Yim. Advanced Traveler Information Systems: Relationship to Traveler Behavior, Chapter 12 in *Assessing the Costs and Benefits of Intelligent Transportation Systems*, Kluwer Academic Publishers, Edited by D. Gillen and D. Levinson, 2004, pp. 218-240.

[cxxxvii] Asad J. Khattak, Xiaohong Pan, Billy Williams, Nagui Rouphail, Yingling Fan. Traveler Information Delivery Mechanisms: Impacts on Consumer Behavior. Paper #08-0776, CD-ROM Transportation Research Board 87th Annual Meeting, Washington, D.C., 2008

Goulias, K.G., T.-G., Kim and O. Pribyl. A longitudinal analysis of awareness and use for advanced traveler information systems. Journal of ITS, vol. 8, no. 1, 2004, pp. 3-17.

[cxxxviii] Asad J. Khattak, Felipe Targa, Youngbin Yim. Advanced Traveler Information Systems: Relationship to Traveler Behavior, Chapter 12 in *Assessing the Costs and Benefits of Intelligent Transportation Systems*, Kluwer Academic Publishers, Edited by D. Gillen and D. Levinson, 2004, pp. 218-240.

[cxxxix] Asad J. Khattak, Felipe Targa, Youngbin Yim. Advanced Traveler Information Systems: Relationship to Traveler Behavior, Chapter 12 in *Assessing the Costs and Benefits of Intelligent Transportation Systems*, Kluwer Academic Publishers, Edited by D. Gillen and D. Levinson, 2004, pp. 218-240.

[cxl] Ben-Akiva M, de Palma A, Kaysi I. Dynamic network models and driver information systems. Transportation Research Part A 1991;25:251-266.

Khattak AJ, Schofer JL, Koppelman FS. Commuters' Enroute Diversion and Return Decisions: Analysis and Implications for Advanced Traveler Information Systems. Transportation Research Part A 1993;27A(2):101-111.

Adler JL, Blue VJ. Toward the Design of Intelligent Traveler Information Systems. Transportation Research Part C: Emerging Technologies 1998;6(3):157-172

[cxli] David Levinson, Hong Huo. Effectiveness of Variable Message Signs, TRB Annual Meeting, 2003.

[cxlii] FHWA. IDAS: Intelligent Transportation Systems Deployment Analysis System. In: Cambridge Systematics, Inc.; 1997.

Program ITS. DynaMIT: Real Time Traffic Estimation and Prediction System. In: Intelligent Transportation Systems Program, Massachusetts Institute of Technology.

Mahmassani HS, Sbayti H, Zhou X. DYNASMART-P Version 1.0 User's Guide. In: Maryland Transportation Initiative, University of Maryland; 2004.

Gardes T, Lunsford ME, May AD, Van Aerde M. Application of the INTEGRATION model to demonstrate the simulation of advanced traveler information systems. In: Transportation Research Board Annual Meeting; 1993; Washington, DC; 1993.

Quadstone. PARAMICS Modeller V3.0 User Guide. Edinburgh, UK: Quadstone Limitied; 2000.

[cxliii] Haselkorn M, Spyridakis J, Conquest L, Barfield W. Surveying commuter behavior as a basis for designing motorist information systems. In: The First Vehicle Navigation and Information Systems Conference, IEEE; 1989; Toronto, Canada; 1989. p. 93-100.

[cxliv] Ben-Akiva M, de Palma A, Kaysi I. Dynamic network models and driver information systems. Transportation Research Part A 1991;25:251-266.

[cxlv] Khattak AJ, Schofer JL, Koppelman FS. Commuters' Enroute Diversion and Return Decisions: Analysis and Implications for Advanced Traveler Information Systems. Transportation Research Part A 1993;27A(2):101-111.

[cxlvi] Adler JL, Blue VJ. Toward the Design of Intelligent Traveler Information Systems. Transportation Research Part C: Emerging Technologies 1998;6(3):157-172

[cxlvii] Targa, F., A.J. Khattak, and Y.B. Yim. Understanding Access and Acquisition of Dynamic Travel Information. *Conference Proceedings*, IGERT 2003 Annual Conference, University of California, Davis, 2003.

Mohamed A. Abdel-Aty, Ryuichi Kitamura, Paul P. Jovanis. Using stated preference data for studying the effect of advanced traffic information on drivers' route choice. Transportation Research Part C, Vol.5, No.1. 1997, pp39-50.

Hani S. Mahmassani, Yu-Hsin Liu. Dynamics of commuting decision behaviour under advanced traveler information systems. Transportation Research Part C, Vol.7, 1999, pp91-107.

William H. Greene, David A. Hensher, John Rose. Accounting for heterogeneity in the variance of unobserved effects in mixed logit models. Transportation Research Part B, Vol.40, 2006, pp75-92.

Karthik K. Srinivasan, Hani S. Mahmassani. Analyzing heterogeneity and unobserved structural effects in route-switching behavior under ATIS: a dynamic kernel logit formulation. Transportation Research Part B, Vol.37, 2003, pp793-814.

[cxlviii] Rong-Chang Jou, Soi-Hoi Lam, Yu-Hsin Liu, Ke-Hong Chen. Route switching behavior on freeways with the provision of different types of real time traffic information. Transportation Research Part A, Vol.39, 2005, pp445-461.

David Levinson, Hong Huo. Effectiveness of Variable Message Signs, TRB Annual Meeting, 2003.

Asad J. Khattak, Youngbin Yim, Linda Stalker Prokopy. Willingness to pay for travel information. Transportation Research Part C, Vol.11, 2003, pp137-159.

Richard H. M. Emmerink, Peter Nijkamp, Piet Rietveld, Jos N. Van Ommeren. Variable message signs and radio traffic information: an integrated empirical analysis of drivers' route choice behaviour. Transportation Research Part A, Vol.30, No.2, 1996, pp135-153.

[cxlix] Ben-Akiva M, de Palma A, Kaysi I. Dynamic network models and driver information systems. Transportation Research Part A 1991;25:251-266.

Levinson D. The value of advanced traveler information systems for route choice. Transportation Research Part C: Emerging Technologies 2003;11(1):75-87.

Al-Deek HM, Khattak AJ, Thananjeyan P. A combined traveler behavior and system performance model with advanced traveler information systems. Transportation Research Part A: Policy and Practice 1998;32(7):479-493

Arnott R, de Palma A, Lindsey R. Does providing information to drivers reduce traffic congestion? Transportation Research Part A 1991;25:309-318.

Kanafani A, Al-Deek HM. A simple model for route guidance benefits. Transportation research Part B 1991;25(3):191-201.

Chen PS, Mahmassani H. A dynamic interactive simulator for the study of commuter behavior under real-time traffic information supply strategies. In: Annual Meeting of Transportation Research Board; 1993; Washington, DC; 1993.

[cl] http://tmcpfs.ops.fhwa.dot.gov/cfprojects/new_detail.cfm?id=35

[cli] http://tmcpfs.ops.fhwa.dot.gov/cfprojects/new_detail.cfm?id=35

[clii] John M. Mounce, Gerald Ullman, Geza Pesti, and Valmon Pezoldt. Guidelines for the evaluation of dynamic message sign performance. Texas Department of Transportation. FWHA Report 0-4772-1. 2006.