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16. Abstract

The objective of this research project was to determine appropriate guidelines and methodology for evaluating dynamic message sign (DMS) performance. National literature reviews and agency surveys were conducted and synthesized for a critical assessment of the state-of-the practice in DMS performance evaluation. DMS performance metrics were established based upon data availability, time of evaluation (pre-post), and environment of application (urban/rural). Both qualitative and quantitative DMS benefits were established with examples of associated analysis tools given and discussed. Case studies were conducted along freeway corridors where DMSs had been implemented in both urban (Houston, Texas) and rural (Amarillo, Texas) environments. The results of these case studies highlighted constraints in both data availability and appropriate analysis procedures. Final guidelines and methodology for DMS performance evaluation were produced emphasizing the limitation to assessment of both qualitative and quantitative benefits. A guidebook of DMS performance evaluation procedures was included as Appendix D in the research report.

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GUIDELINES FOR THE EVALUATION OF DYNAMIC MESSAGE SIGN PERFORMANCE

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data, opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), Federal Highway Administration (FHWA), The Texas A&M University System, or the Texas Transportation Institute (TTI). This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof. The researcher in charge of the project was Dr. John M. Mounce, P.E. #42656.

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- Mr. Tai Nguyen, P.E. (TxDOT Fort Worth District);
- Mr. David Rodrigues (TxDOT San Antonio District); and
- Mr. Wade Odell, P.E. (TxDOT Research and Technology Implementation Office), research engineer.

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CHAPTER 1: INTRODUCTION

BACKGROUND

Dynamic message signs (DMSs), also referred to as changeable message signs (CMSs) and variable message signs (VMSs), have been utilized for almost 40 years to communicate traffic information to motorists *(1)*. DMS systems are an essential element of many advanced traveler information and traffic management systems and a primary component of intelligent transportation systems (ITS) architecture *(2)*. While the majority of DMS deployment and application has been in urban areas, the last 10 years have seen extensive implementation in rural roadway environments as well *(3)*. DMSs allow for the dissemination of real-time traffic information to motorists. In urban areas, DMSs are typically used to inform motorists of traffic conditions to be encountered (i.e., expected delays, estimated travel times, diversion routes, and lane closures) and have become an increasingly important source of motorist information during incidents, special events, and work zone traffic control. In rural areas, the focus of DMS utilization has been on displaying timely roadway and environmental condition information to enhance motorist safety.

The value of DMS systems, or any medium to communicate traffic information, is dependent upon ensuring that multiple criteria are satisfied, including:

1. The information disseminated is viable, reliable, and timely.
2. The messages conveying the information are legible, readable, appropriately placed, and comprehended by motorists.
3. Motorists believe the information provided to be credible and useful, are willing and able to respond to it, and do, in fact, respond appropriately to the information provided.

To the extent that a DMS system is deficient in meeting any of these conditions, the merit of the system will be compromised and potential advantages diminished.

More than 25 years of research has addressed electronic sign design, size, location, transmission, and format as well as message construction, content, and display for virtually all conceivable roadway incident scenarios in both urban and rural settings *(4)*. Ongoing studies continue to examine operating policies and procedures to ensure message display timeliness and accuracy and to optimize the comprehension of DMS displays *(5, 6, 7, 8)*. The vast literature pertaining to all of these issues has provided transportation agencies with sufficient information to allow them to be confident that accurate, timely messages can be designed and displayed in a manner that will be correctly understood by most motorists and that can, if all the messages are heeded, produce the desired impacts on traffic flow, incident management, and overall improvements in motorist safety and convenience. Thus, though additional research and implementation issues may still need to be addressed as DMS implementation evolves, pertinent information and experience are readily available to provide confidence that Criteria 1 and 2, above, can be met. Less confidence is warranted with regard to Criteria 3. Despite the significant progress realized in recent years with regard to DMS design and deployment, a critical issue that has received less attention and about which much less is known is the actual influence of DMS systems either during periods of congestion or incidents, or under normal traffic conditions. If DMS systems cannot be shown to have measurable effects on traffic conditions and/or public perception of those conditions, the value of even the best designed systems will be subject to question.

GOALS

The goal of this research project was to provide the Texas Department of Transportation (TxDOT) with objective guidelines and a methodological framework for evaluating DMS performance. These guidelines include a range of application locations (urban-rural), traffic flow conditions (incident-normal), level of assessment (quantitative-qualitative), time period of analysis (before-after), and availability of data to address all contingency scenarios. These guidelines are to allow TxDOT engineers to measure the effectiveness of existing DMS systems and to validate the implementation and efficient operation of future systems. The guidebook was written and produced as a stand-alone document to be disseminated through the TxDOT Annual ITS Technical Committee Meeting by the Traffic Management Section of the Traffic Operations Division, the Annual Meeting of the Intelligent Transportation Systems Texas Chapter, and other mechanisms.

OBJECTIVES

The objectives of the research project were to identify, gather, and analyze quantitative and qualitative measures for various evaluation contingencies that reflect different data availability situations and deployment status, specifically both before and after DMS operational implementation. Evaluation contingencies varied among different DMS deployment environments, i.e., rural or urban. A preliminary outline of DMS performance guidelines and contingency evaluation methodologies was to be developed and presented to a TxDOT advisory panel for critique, approval, and, as needed, modification prior to proceeding with validation testing.

The research team selected case study sites in both Houston, representing urban traffic conditions with DMS operation, and Amarillo, representing rural traffic conditions with DMS operation. Evaluation methodologies were to be tested at these sites with available data to assess DMS performance. Results were to be used to critically analyze and modify the previous preliminary guidelines and methodology. Both a summary guide for DMS performance evaluation and a final report detailing all project activity, findings, and recommendations were to be prepared and submitted as deliverables from the research project.

The remainder of this report details all work activity associated with the completion of the stated tasks to fulfill the project goals and objectives. To accomplish the stated objectives of the research project, the research approach consists of 10 primary tasks. Each task statement is given below:

- **Task A—Literature Review**
  Assimilate and review available published literature and ongoing research on DMSs and other ITS component performance evaluations and related methodologies for assessment.
- **Task B—Agency Survey**
  Conduct a survey of agencies, statewide and national, responsible for DMS operations and performance.
- **Task C—Synthesis of Findings**
  Critically analyze and synthesize all obtained information regarding DMS performance and/or evaluation methodology.
- **Task D—DMS Performance Data Taxonomy**
  Prepare a taxonomy of data requirements for contingency DMS evaluations for comparison to an inventory of available data.

- **Task E—Preliminary Guidelines**

  Establish a preliminary outline of DMS performance guidelines and contingency evaluation methodology.
- **Task F—Site Selection/Data Collection**

  Select both urban and rural case study sites, and collect associated DMS performance data.
- **Task G—Study Validation**

  Conduct both urban and rural case studies of DMS performance utilizing contingency evaluation methodology.
- **Task H—Finalize Evaluation Methodology**

  Analyze and refine, as needed, the previously established preliminary guidelines and framework of contingency evaluation methodology.
- **Task I—Prepare/Submit Guide**

  Prepare a DMS performance and evaluation methodology guide.
- **Task J—Prepare/Submit Reports**

  Prepare research and project summary reports.

CHAPTER 2: LITERATURE REVIEW

Dynamic message signs can be effective tools in communicating traffic information to motorists. DMSs are often used to disseminate real-time traffic information, enabling agencies to keep motorists aware of current roadway conditions. A common use of DMSs is route guidance. Considered an effective tool by the Federal Highway Administration (FHWA), DMSs warn drivers of congested roadways and can provide alternate route suggestions.

Significant benefits possible through route guidance are travel time reductions, increased speeds, and decreased number of stops (*1*). In addition to route guidance, DMSs are particularly valuable in other scenarios. A major objective of DMSs is to reduce the delay and risks caused by crashes, stalls, disabled vehicles, and construction, etc. (*2*). The real-time capabilities of DMSs allow traffic information in response to these incident conditions to be quickly displayed. Route guidance information provided on DMSs is likely to be particularly beneficial to travelers on long trips, using multiple modes, or confronted with several route choices. Visitors and unfamiliar travelers, in particular, may find DMSs useful (*1*).

Because DMSs have numerous applications and benefits, it is necessary to consider the goals of a particular DMS before evaluating its performance. Benefits will vary depending upon the intended use of the DMS, its location (e.g., urban versus rural), and its period of use. Benefits achieved by DMSs, including improved safety, time savings, increased throughput, cost savings, reduced emissions, and reduced fuel consumption, can be quantified to determine the effectiveness of the DMS (*3*). It is also necessary to consider qualitative measures, such as customer satisfaction, when evaluating DMSs. Consideration of the variables above can be used both to establish a framework for evaluation of DMS systems and be applied to evaluate the benefits of individual DMSs in multiple settings.

DYNAMIC MESSAGE SIGN APPLICATIONS

Currently, no national policy exists on the display of messages on DMSs. Agencies establish individual policies and guidelines through the recommended practices derived from current research, ITS and stationary signing policies in the *Manual on Uniform Traffic Control Devices*

(MUTCD), and personal experience. None of the traffic management centers operating in the state of Texas currently have written policies regarding the display of DMS messages. Some agencies, however, do have guidelines they follow (*1*). With the absence of a national policy, disagreements on the appropriate use of DMSs exist in several areas. A review of current DMS applications follows.

Traffic-Related Messages

Dudek classifies the use of DMSs for traffic-related messages into four broad categories *(4)*:

- 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 (included here is the operation of directional lanes, tunnels, bridges, tollbooths and weigh stations, etc.).

The information summarized below is based on guidelines from several state departments of transportation and various researchers. Though not specifically tied to Dudek's classification, each of the applications cited here is consistent with one or more of Dudek's categories.

Emergencies

DMSs can convey emergency evacuations and emergency road closures to the traveling public (*5, 6, 7*). An "emergency" situation may be issued by several agencies including the Department of Emergency Management, state departments of transportation, local law enforcement, or the military. Emergencies should have a high priority of display on DMSs (*5*).

Closures

DMSs are also used to display information regarding routine road, ramp, lane, or shoulder closures. Alternate route information should be provided when a complete closure is required and detours are necessary (*5, 6, 8*). Closures are often caused by construction and maintenance activities. In addition to warnings of roadway closures, DMSs are often used to inform motorists of the presence of construction and work zone operations (*5, 6, 7*).

Special Events

Advance notice of a special event causing traffic or safety implications to travelers is often displayed on DMSs. 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 (*5, 6, 7*).

Incidents

Notifying drivers of incidents or crashes on the roadway is an important use of DMSs (*5, 6, 7, 8*). DMS use for incident management is a major step toward achieving the goals of ITS. Motorists aware of upcoming incident conditions are given the opportunity to divert to alternate routes. This has the potential to lessen delays to the individual motorist and relieve congestion on the primary route. Wei supports the common belief that about half of all congestion is induced by incidents (*2*). Similarly, Hatcher et al. suggest that 60 percent of delay is directly linked to nonrecurring incidents and crashes (*9*). 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 (*6, 8*). To determine the personal impact of the incidents and accidents, motorists desire exact locations to be displayed on DMSs (*10*). This allows drivers to evaluate the effects of the incident on their individual travel time and route decisions. Durkop and Balke surveyed motorists regarding the display of messages that describe the specifics of incident scenarios. Example messages include “Police en route,” “Police notified,” etc. Motorists reacted favorably to the dissemination of incident-specific information. State departments of transportation and other transportation agencies agreed, however, that a DMS is not the preferred medium for this type of incident information due to its limited message size and issues in obtaining accurate up-to-date incident specifics (*11*).

Congestion

Similarly, DMS messages can be used to warn motorists of significant delays or congestion on the roadway ahead unrelated to a specific incident (*7*). These warnings may be accompanied by suggested alternate routes or additional travel information (*5*). Driver reactions to congestion, including diversion to alternate routes, are largely impacted by the degree of congestion ahead.

Communicating delays and congestion to motorists in a comprehensible manner can be complicated. Current methods of quantifying congestion include calculating average travel speeds and times. Travel speeds on the route ahead are displayed on DMSs to convey the current extent of congestion. Similarly, agencies may display travel times from the location of the DMS to a specified location (*6*). The goal of displaying these particular measures is to advise motorists of the traffic conditions and suggest alternate travel routes that may be taken when travel is deemed unsatisfactory by the individual driver. These quantitative measures are not the only method of disseminating traffic information, and not necessarily the best. Dudek et al. suggest that motorists prefer qualitative information such as location, length, and degree of congestion to other quantitative measures such as travel time and speed (*12*). Motorists better understand the qualitative information and are able to make well-informed decisions regarding route choice. Whether quantitative or qualitative information is displayed on the DMS, it is important that all real-time traffic information be kept up to date (*7*).

Other Uses

Several other scenarios warrant the use of DMSs. A very common use of DMSs is to display weather-related information that affects traffic. DMSs may be used to advise motorists of severe weather or environmental conditions in the area, especially those requiring a change in the motorist's driving behavior (*5, 6*). Traffic conditions can also be affected by rail systems in the area. For example, railroad grade crossing information is available via DMSs to motorists in the San Antonio area (*8*). This allows motorists to alter their routes to avoid a lengthy wait for a crossing train. The Kentucky Transportation Center also notes several additional uses of DMSs. Appropriate uses include information warning of changes in alignment or surface conditions, vehicle restrictions, and advance notice of new traffic control devices (*7*).

Restrictions in DMS Use

The Kentucky Transportation Center notes several *inappropriate* uses of DMSs *(7)*. Of particular importance is the use of DMS messages to restate or replace required permanent signage. This could result in serious problems of information overload and driver inattention to DMSs. Specifically, DMS messages should not replace static signs, regulatory signs, pavement markings, standard traffic control devices, conventional warnings, or guide signs. They should not be used to replace a lighted arrow board. DMSs should not display test messages or weather-related activities such as deicing. Contrary to much common use, as indicated by Dudek's first category of DMS use (*4*), Walton et al. contend that DMSs should *not* be used to describe a recurrent condition such as rush-hour traffic (*7*).

Non-Traffic-Related Messages

Policies regarding the display of non-traffic-related messages on DMSs are not consistent. Although there appears to be a general consensus among professionals that non-traffic-related messages should not be displayed on DMSs, interpretation of the term "traffic related" varies widely (*13*). The *Manual on Uniform Traffic Control Devices* states that DMSs should not be used to display information other than regulatory, warning, and guidance information related to traffic control (*14*). Some policies state that messages displayed on DMSs must require motorists to take an action or alter their driving behavior (*5, 15*). Consensus on how strictly to follow these guidelines, however, has thus far not been achieved. There is a consensus that DMSs should not be used to advertise commercial events or entities (*5, 6, 7, 13*). Additionally, tourist information should not be provided via DMSs (*6*). Consensus breaks down, and inconsistencies arise, with regard to the use of DMSs for displaying public service announcements.

Public Service Announcements

The use of DMSs for public service announcements is accepted by several agencies; however, the type of messages that are permitted varies. Public service announcements include brief messages that do not require an immediate response but encourage drivers to alter a future driving behavior. Due to the lack of urgency associated with public service announcements, these messages are generally given low priority. The Oregon Department of Transportation gives public service announcements the very lowest priority and displays them only in off-peak periods for a maximum of 5 hours a day and 5 days a month. In addition to limiting the time allowed for the display of public service announcements, these messages are generally restricted to permanent DMSs and not permitted on portable DMSs (*6*). Even with the limitations above, the use of DMSs to display public service announcements is often questioned. Past public service announcements displayed on DMSs in California have received very negative feedback from motorists (*16*).

Safety messages are considered a type of public service announcement and are very often displayed on DMSs. Safety messages are considered acceptable in most situations (*5, 7, 15, 16*). However, some agencies do not permit any type of public service announcement, including general traffic safety messages (*7*). Most agencies require careful consideration of safety messages before they are posted on DMSs (*5*). Some recommend that safety messages and slogans be displayed only as part of a particular, specific campaign (*15*). Time limits of 3 weeks are often set to avoid the long-term display of the safety messages (*7, 15*).

Emergency and security information constitutes another type of public service announcement that may be permitted on DMSs. The *MUTCD* permits the use of these message types provided that they are transportation related and require actions by motorists. It is still necessary that these messages follow good practices established for all other message displays on DMSs. When emergency messages are displayed by agencies, it is imperative that guidelines be established for the development of the messages. A clear understanding of who issues the security and emergency alerts, the areas affected by the alert, and the importance of the alert relative to other general traffic information is necessary. Rules regarding the preemption or discontinuation of the emergency or security message must be understood by DMS operators (*17*).

AMBER Alerts represent a unique type of public service announcement. The Texas Department of Public Safety issues AMBER Alerts when a child is kidnapped. The purpose of these alerts is to advise individuals in the area of the crime and provide pertinent information. The alerts are sent to the Texas Department of Transportation, as well as numerous other agencies that can communicate important information to the public (*18*). Descriptions of a suspect's vehicle and license plate information may be posted on DMSs to alert the public. While supporting the AMBER Plan and permitting the display of AMBER Alerts on DMSs, FHWA notes that this may not be the most effective or safe method to communicate with the public. A study of motorist awareness of DMS AMBER Alert messages was conducted by the University of

Minnesota's Intelligent Transportation Systems Institute. Researchers found that only 8.3 percent of surveyed motorists were able to recall the alert, description of the vehicle, and five or six license plate characters; 51.7 percent could recall the vehicle and a few license plate characters. Researchers concluded that drivers experienced great difficulty in recalling license plate characters. A recommendation was made to post AMBER Alert messages on DMSs referring motorists to a highway advisory radio station for alert details, including further information on the suspect and the kidnapped child (*19*). Due to the uncertainty associated with displaying these alerts on DMSs, FHWA only considers the AMBER Plans acceptable if they follow the subsequent criteria. It is imperative that guidelines are established by all agencies displaying AMBER Alerts. The AMBER Plan in the area must be well established, and the agency must be aware of who is responsible for issuing an AMBER Alert. The location and duration of the alert must also be known before displaying this type of public service announcement on DMSs. If an AMBER Alert creates an adverse traffic impact, the message must be discontinued.

Guidelines must also address criteria for removing messages when traffic is interrupted (*20*). Other public service announcements that are displayed on DMSs in some areas include air quality information and public law messages. Ozone alerts and other air quality information have been displayed in some cities to warn motorists of the hazardous conditions. The display of this information is limited to the 24-hour period when the alert is in effect. DMS messages regarding changes in public laws should be brief and only displayed when necessary (*6*).

Blank Message Displays

A lack of consensus about how to effectively use a DMS when no message is warranted is evident. During non-incident conditions, some agencies leave the DMS blank, while others display generic messages such as time and temperature. Leaving a DMS blank can benefit the responsible agencies in several ways. Maintenance costs and energy costs decrease when a DMS is left blank. The functionality of DMSs is also improved. Motorists are not subject to information overload, and a message is more likely to attract their attention when it is displayed.

Furthermore, messages displayed for long periods of time tend to be ignored and considered unhelpful by motorists. Leaving a DMS blank can also have its disadvantages as well. Motorists often believe that a DMS is not functioning properly because of its blank state. They would prefer to see confirmation that the sign is working. Signs that remain blank for extended periods are also perceived to be a waste of money by taxpayers (*1*). Inconsistencies in policy regarding DMS displays during non-incident conditions are illustrated in Dudek's 1997 report indicating that 77 percent of 26 transportation agencies surveyed had a policy of leaving DMSs blank during non-incident scenarios (*16*). More recently, a survey by the University Transportation Center for Alabama reported that 39 percent of the 13 transportation agencies left DMSs blank (*13*).

LOCATION OF DYNAMIC MESSAGE SIGNS

The locations of DMSs are often determined through unwritten current practice and general policies. Agencies seldom implement methods to ensure that specific DMS locations are optimal. Two applicable methods for optimizing DMS locations include genetic algorithms and integer programming.

Abbas and McCoy have researched the use of genetic algorithms for this purpose. Their decision to implement genetic algorithms was based on several factors. Genetic algorithms give several solutions, not just one "best" solution. Additionally, the constraints required in genetic algorithms are less than those necessary to find an integer programming solution (*21*). To determine the optimal DMS location, the benefits of DMSs must be evaluated at all possible locations. Abbas and McCoy define the potential benefits of DMSs at a diversion point as the sum of the reduction in delay and accidents on the freeway upstream of an incident plus the changes in delay and accidents on the freeway section downstream of an incident. These benefits were maximized through a computer program written to apply genetic algorithms to optimize DMS locations. The program written by Abbas optimizes DMS locations, calculates the total adjusted benefits, and determines the installation order of DMSs. DMS locations with the highest benefits are recommended first for installation. If the number of DMSs to install is not predetermined, the genetic-algorithm program recommends a maximum number of DMSs. This is done through the calculation of benefit-cost ratios for each quantity of DMSs at the optimal locations. Researchers do not recommend installing a quantity of DMSs that produces a benefit-cost ratio less than one. The methodology used by Abbas and McCoy accurately determines the optimal locations and quantities of DMSs to be installed on a traffic network. It is important to note that the application of this methodology requires knowledge of the origin-destination trip matrix on the freeway and the characteristics of the freeway incidents occurring on it (*21*).

Chiu et al. researched the use of integer programming to optimize DMS locations. With a given number of DMSs, possible locations were determined and analyzed. Optimal locations were chosen so that the long-run expectation of benefits was satisfied under stochastically occurring incident scenarios. The main benefit of correctly locating DMSs is the reduction in total user travel time. Implementation of the programming requires numerous inputs that describe geometry and traffic patterns of the highway network to be analyzed. The problem is simulated using a dynamic traffic assignment algorithm, which aides in determining the effectiveness of DMS locations. It is necessary that each location has a high probability of capturing the randomly occurring incidents and can then effectively divert traffic. The final solution generated by the integer-programming model determines the optimal location for all incident scenarios on the system. The solution may not be optimal for an individual incident (*22*).

EVALUATING DYNAMIC MESSAGE SIGNS

To understand the impacts of DMSs on a transportation system, it is necessary to evaluate DMS performance. Quantifying DMS benefits assists in making future investment decisions and optimizing the current system. To begin evaluating any intelligent transportation system, it is necessary to understand the goals of the system (*23*). The National ITS Architecture defines six major goals of ITS. The first goal of any ITS element is to improve operational efficiency and capacity of the system. Secondly, mobility, convenience, and comfort on the system should improve. Safety on this system should improve as a result of an ITS project. Another goal is the reduction of energy consumption and environmental costs.

Economic productivity of individuals, organizations, and the economy as a whole should be increased as a result of ITS implementation. Finally, an environment should be created in which

ITS development and deployment can flourish (*1*). In 2002, ITS America defined an additional goal of intelligent transportation systems—security. Security has become an important issue in the United States and can be addressed through ITS applications. It is necessary that the transportation industry aid in maintaining national security where appropriate. Among the transportation-related security issues that can be addressed by ITS are: vehicle, transit, and cargo surveillance and assisting in the quick and appropriate response to system disruptions including evacuation plans, rescues, quarantines, etc. (*24*).

Evaluating DMSs requires unique considerations not typically necessary in other transportation improvement projects. DMSs are intended to reduce delays and risks associated with incidents or unique conditions. Because incidents occur randomly, measures focusing on peak-period needs are not well suited for DMS evaluation. It is preferable to use measures that consider the impact of the incident and other unique operational conditions (*9*). Additionally, motorist response to DMSs is necessary to implement an effective system. Thus, consideration of motorist reactions to DMSs is essential in creating performance measures. These qualitative measures are sometimes difficult to compare but are just as imperative as other more quantitative indicators.

Thorough evaluation of DMS performance requires that every group impacted by the DMS should be identified; impacts should not be limited to drivers. The time frame of the DMS system design should be used to determine when the intended benefits were expected to be achieved. The impacts of the DMS should be measured at this point in time (*23*).

Performance Metrics

Poe has identified three specific types of performance measures for evaluation of any ITS. The first encompasses point measures. Point measures are determined at a specific site on the system. These include values such as travel speed and traffic volume. Poe defines a second type as link-based measures. Examples include measures of travel time, average speed, or delay. Finally, corridor measures can be used in the evaluation process. These measures evaluate system performance from day to day. They include average person speed, person delay, or person hours of travel (*25*). Turner and Stockton also have characterized evaluation measures, defining two specific types. The first type is considered output measures; these include aggregate characteristics of the system, including traffic flow, speed, or travel time on the network. Secondly, outcome measures are defined to characterize the impacts of the system at the individual traveler level (*23*).

Evaluation measures addressing the National ITS Architecture goals have been explored by several researchers, notably FHWA (*1*, *26*), Gillen and Li (*27*), and Turner et al. (*28*). Table 1 provides a compilation of evaluation measures relevant to each ITS Architecture goal derived from the four sources noted above. In an effort to simplify the evaluation process, FHWA has created a list of a "few good measures," or performance metrics deemed sufficiently robust to quantify an entire ITS program. These measures had to be acceptable, understandable, easily measured, and address the National ITS Architecture goals. FHWA included the following measures:

- crashes,
- fatalities,
- travel time,
- throughput,
- user satisfaction and acceptance, and
- cost.

Tarry has further defined performance indicators expressly for evaluation of DMSs (*29*). These indicators, identified in Table 2, address the issues that arise specifically in DMS systems.

Motorist Response

A few performance metrics noted by researchers address the qualitative benefits of DMSs, e.g., public acceptance. However, these measures are difficult to obtain and provide a significant challenge in evaluating DMSs. To achieve an effective use of DMSs, it is important that motorists respond to the displayed messages. In order for DMSs to produce appropriate driver response, the messages must be meaningful, accurate, timely, and useful (*12*). If the messages displayed on DMSs have not adhered to these guidelines, driver credibility will be lost.

Table 1. Compilation of ITS Measures and Metrics.

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

Table 2. Example Performance Indicators for Dynamic Message Signs.

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

Source (*29*)

Dudek further specifies DMS problems that lose the motorists' confidence (*4*):

- displaying inaccurate or unreliable information (*5*);
- displaying information too late for drivers to make an appropriate response;
- displaying messages drivers do not understand;
- displaying messages that are too long for drivers to read (*30*);
- not informing drivers of major incidents;
- telling drivers something they already know;
- displaying information not related to environmental, roadway, or traffic conditions, or routing; and
- displaying garbled messages.

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

A study in northern California reported that half of motorists surveyed were often influenced by DMSs, while two-fifths were occasionally influenced. Similarly, half of motorists surveyed in northern Virginia indicated they were influenced by DMSs (*10*). This percentage is remarkably high considering that a third of the motorists in this study had previously experienced errors with the signs. A study by Stockton et al. reported that the majority of Dallas motorists understood the DMSs in place, and 82 percent of these motorists were influenced by the signs (*31*). These large influence rates are indicative of effective DMS messages. Negative motorist reactions to DMSs cannot be linked to any particular demographic variables (*10*).

Diversion Responses

DMSs may be used to divert traffic to a secondary route when the road ahead is severely congested or drivers will experience significant delays. Within the state of Texas, soft diversion is used to encourage motorists to take a specified alternate route (*1*). This method has often proven effective in moving traffic to an alternate route. Weaver et al. have reported diversion rates as high as 56 percent through the use of DMSs (*32*). The willingness of drivers to follow DMS suggestions and divert depends on several conditions. The primary concern of drivers is the characteristics of the alternate route. Motorists are more willing to divert if they deem the secondary route suitable (*12*, *32*). If motorists believe the alternate route will have a similar amount of congestion as their current route, they will not be willing to divert (*10*). If motorists suspect the secondary route will not provide shorter travel times, they will not divert (*10*). Additionally, if the length of the secondary route is considerably greater, drivers will not divert regardless of travel time. Drivers are often unable to quantify the delay they will experience on their current route. Therefore, they do not believe a lengthier secondary route will provide them with travel time savings (*33*). Peters et al. researched motorists' diversion decisions in relation to characteristics of the alternate route. A link could not be established between route choice and knowledge of the alternate route conditions. However, drivers better informed of alternate route characteristics were able to reach their decision in a timelier manner (*34*). Motorists have also demonstrated a fear of getting lost when diverting from their current route (*10*). Unfamiliarity with alternate routes is a significant deterrent to diversion (*32*, *33*, *35*). To encourage drivers' willingness to divert, sufficient guidance must be provided to aid in reaching their destination (*32*). Motorists who are unfamiliar with either the current or alternate route will divert more willingly than those comfortable with their chosen route (*35*). Motorists comfortable with the area may not divert to the specified secondary route because they already have an alternate route chosen (*10*).

Drivers also are not willing to divert if the conditions of the roadway ahead are not communicated to the driver *(12)*. Motorists desire a reason for them to take a particular action. DMS messages simply stating "Congestion Ahead" may not describe a suitable scenario for diversion. Messages with increased detail allow motorists to quantify the amount of delay on their chosen route. Drivers must have confidence in this information provided by DMSs, or suggestions for diversion will be ignored. Additionally, the messages must reach the motorists. If DMSs are ignored by motorists, responses to diversion routes will be minimal *(34)*. To increase diversion responses, the use of two DMSs to clarify route choices was tested. Repeating diversion messages at two locations with DMSs did not prove effective in increasing driver diversion rates to the alternate route *(36)*.

A few other factors have consistently characterized driver responses to DMS diversion suggestions. Motorists attending events with fixed starting times were more willing to divert to alternate routes *(35, 36)*. Delay in their current route might cause drivers to be late to their event. Since it is more important that these drivers reduce their delay and arrive on time, they will more willingly divert to alternate routes. Diversion percentages also increase during summer months, on Thursday and Friday, and in off-peak conditions *(33)*.

Stated Preference Surveys

Surveys are often conducted to determine driver reaction to DMSs. Among the survey methods employed to evaluate DMS benefits are stated preference surveys. This type of survey asks participants how they would react in a given hypothetical situation, rather than quantifying actual motorist choices. Motorist preferences in relation to DMSs may then be quantified *(37)*.
In designing a stated preference survey, several factors must be considered. First, respondents should be provided with realistic choices. If this is not possible, researchers should acknowledge to the respondents that this is the case and that they are simply taking preferences. It is also important that surveys are not overly long or complex. This helps ensure that responses represent actual preferences and are not a result of confused participants *(37)*. Stated preference survey interviews can be implemented in person or via telephone, mail-outs, or handouts. As with all surveys, sufficient pretests of the survey instruments should be conducted to identify any necessary changes to the questionnaire prior to full-scale application *(37)*.

Analysis

Benefits achieved through the implementation of DMSs have been quantified in several ways. These benefits must be analyzed to determine the effectiveness of a DMS. There are three common methods for analyzing any ITS improvement, including DMSs. These include benefit-cost analysis, impact analysis, and cost-effectiveness analysis. The most common of these methods is benefit-cost analysis. This method weighs the costs of a project to the benefits achieved. In this manner, desired projects yield the greatest net social-economic benefit. Cost-effectiveness analysis does not determine the net social benefit but compares projects based on their cost-efficiency. A limiting factor of these approaches is the need for quantitative information. Any qualitative benefits achieved through the DMS cannot be included in these analyses. As stated previously, public acceptance of DMSs is very important for success, but this qualitative measure is very difficult to assess within the context of the analysis approach discussed here (*27*). Finally, impact analysis focuses entirely on the benefits of the project with no regard to the costs.

CHAPTER 3: AGENCY SURVEY

INTRODUCTION

The purpose of this task is to determine the state-of-the-practice of DMS implementation and performance evaluation, and to assess professional opinions regarding the benefits and challenges of evaluating DMSs. Based on the literature review, little information is available on evaluating DMSs and what types of measures of effectiveness are needed for this type of evaluation; therefore, an agency survey was conducted to gather additional information not readily available in the published literature.

SURVEY DEVELOPMENT AND ADMINISTRATION

The survey was developed to establish the following:

- extent and details concerning DMS implementation;
- agency use of both quantitative and qualitative measures of effectiveness in assessment of DMS performance;
- existence, background, and application of guidelines for DMS performance evaluation; and
- data requirements and availability to support DMS performance guidelines and evaluation methodology.

Based on these goals, questions were developed for an online survey. Additional questions were included in the survey to assess opinions on the benefits and challenges of evaluating DMSs, and suggestions for evaluating DMSs. The survey targeted ITS professionals from agencies, statewide and national, responsible for DMS implementation, operation, and evaluation. A list of agency contacts responsible for DMS systems was compiled from previous Texas Transportation Institute (TTI) and other national DMS research. An email sent to the compiled list (80 contacts) explained the purpose of this research and provided a link to a survey available for completion on the Internet. Follow-up phone calls were made to maximize the response and to gather any additional support material. Researchers received a total of 15 responses from nine states, five Texas Department of Transportation districts, and one city agency.

RESULTS

The results of the survey responses are included below each question. The enclosed paragraphs following each question list the responses made by the survey participants.

1. What procedures/criteria are used by your agency to fund DMSs?	
Gene Glotzbach Florida Department of Transportation (DOT)	We do not have any procedures/criteria. It is based on the need to provide information to the public about highway condition in highly congested facilities. The district with the most congestion facilities provided district managed funds to provide systems to manage and operate their congested facilities. The DMSs were a part of the management system to provide feedback to the public. We have since developed an ITS deployment plan that provides for the expenditure of over $500 million for the deployment of ITS. A major part of the funding will go to the deployment of ITS.
Nancy Albright Kentucky Transportation Cabinet	Congestion Mitigation and Air Quality (CMAQ) eligibility part of a larger freeway project, either expansion of transportation management, local need and desire to communicate information to drivers.
Tai Nguyen TxDOT Fort Worth District	The DMS is one of the important ITS elements in the "Fort Worth Regional Intelligent Transportation System Plan." To implement the DMS system, we use two different funding sources: one is through the freeway reconstruction projects and through Dallas-Fort Worth CMAQ dedicated fund for a non-attainment area.
Edgar Fino TxDOT El Paso District	The El Paso District has used CMAQ funding. We are installing the DMSs under major roadway construction projects.

Question 2. What procedures/criteria are used by your agency to locate DMSs?
The majority of the respondents locate DMSs in advance of driver decision points and/or major interchanges. Other criteria included high traffic volumes and input from "locals."

2. What procedures/criteria are used by your agency to locate DMSs?	
Mark Demidovich Georgia DOT	We locate DMSs such that a driver can see the sign from 1000 feet away, and read it at 900 feet. We do not place them in horizontal curves. We try to place them 1.25-1.5 miles in advance of a major alternate road decision point. We do not place them according to accident history or volume.
Carlton Allen TxDOT Houston District	Several criteria are considered when determining new locations: 1) Locations of existing DMSs 2) Traffic volumes 3) Freeway geometry DMSs are placed so as to maximize the ability to divert traffic to other freeways during incidents or construction. So, the sign or signs are installed upstream of major freeway interchanges.
Jesus Leal TxDOT Pharr District	We have normally located most of them at major route interchanges and at areas with large average daily traffic (ADT) with merging and diverging traffic.
Elizabeth Ramirez City of Dallas	We used data from the 911 database with global positioning system (GPS) locations and determined the number of incidents per mile on freeway segments. We then determined what arterials would need advance notice by bypass incidents on these freeway segments.

Charlie Cardenas TxDOT Corpus Christi District	Procedures to locate a DMS are to place them prior to a heavy traffic volume area so that the motorist has enough time to read the message and make a decision as to what action to take. Usually before a major interchange. Also, we placed them near hazardous areas to inform motorists of refinery emergencies. Hurricane evacuation is also a big concern; DMSs are placed on both sides of the JFK and US 181 causeways.
Michael Floberg Kansas DOT	Currently, we have not developed criteria related to crashes or volumes. Currently, our criteria are decision points in the urban areas and also in the rural areas. The Kansas DOT has assigned priority corridors in our state that help us determine our first deployment sites.
Kelly Damron North Carolina DOT	Yes—more one subjective way—locals know where they are needed. Equity formula (for funding distribution across the state) plays in too.
Navin Nageli Colorado DOT	If Regional ITS Strategic Plans are available, they identify sign locations based on ITS needs for traffic and incident management and traveler information. In addition, the Colorado DOT ITS Branch is in the process of developing ITS deployment guidelines that address deployment need among various tiers of highways.
Gary Thomas California DOT (Caltrans)	The signs are placed in advance of decision points such as highways. This will allow drivers opportunity to take the best appropriate action or respond to the message displayed on the sign. DMSs are located in advance of decision points. Junctions of interstate with interstate, exits to possible alternate routes on parallel arterials, alternative interstate routes, express and local lanes.
Jeff Galas Illinois DOT	Normally high volume areas.
McCarthy K. Braxton Ohio DOT	I don't know that we do have any documented process for locating DMSs. Each district has probably done things differently, but I imagine crashes and volumes play a part in the decision process. I think the primary criterion is to locate a DMS where a motorist can read the sign and have enough time to be able to make a decision on an alternate route. So, a primary location for a sign would be a decision point.
Gene Glotzbach Florida DOT	Volumes, prior to logical route decision locations for drivers, and access to power and communication.
Nancy Albright Kentucky Transportation Cabinet	Volumes, prior to logical route decision locations for drivers, and access to power and communication.
Tai Nguyen TxDOT Fort Worth District	DMSs are located before an alternate route decision point throughout the countywide system, such as major interchanges or off ramps to major streets.
Edgar Fino TxDOT El Paso District	We try to install the DMS in advance of the off ramps so that we can notify the traveling public when they need to get off the main lanes or they can go on their own and take an alternate route.

Question 3. Has your agency's DMS effectiveness been evaluated?
Three respondents said that their DMSs had been evaluated.

3. Has your agency's DMS effectiveness been evaluated?	
Mark Demidovich Georgia DOT	Yes
Carlton Allen TxDOT Houston District	No

Jesus Leal TxDOT Pharr District	No
Elizabeth Ramirez City of Dallas	No
Charlie Cardenas TxDOT Corpus Christi District	No
Michael Floberg Kansas DOT	No
Kelly Damron North Carolina DOT	No
Navin Nageli Colorado DOT	Yes
Gary Thomas California DOT	No
Jeff Galas Illinois DOT	No
McCarthy K. Braxton Ohio DOT	No
Gene Glotzbach Florida DOT	No
Nancy Albright Kentucky Transportation Cabinet	Yes
Tai Nguyen TxDOT Fort Worth District	No
Edgar Fino TxDOT El Paso District	No

Question 4. What quantitative and/or qualitative measures of effectiveness were used in the evaluation? Two respondents conducted a user survey/focus group, and the other conducted case studies to evaluate reduction in traffic crashes.

4. What quantitative and/or qualitative measures of effectiveness were used in the evaluation?	
Mark Demidovich Georgia DOT	We did a user survey as part of an overall survey on the effectiveness of our entire NaviGAtor program. We asked the users if they used the signs to alter their routes, alter their mode of travel, or otherwise. We also asked if they felt the signs were accurate (all, most, some, hardly ever) of the time. We did not look into quantitative measures such as reduction in crashes.
Navin Nageli Colorado DOT	We are in the process of conducting a series of case studies to evaluate incident management. This includes effectiveness of incident information dissemination using DMSs, highway advisory radio (HAR), local media, etc. So far, one case study has shown a reduction in traffic by 10 percent by disseminating information. How much of this is directly attributable to DMSs is not clear at this time. More case studies will be conducted and incorporate CORSIM modeling.

Nancy Albright Kentucky Transportation Cabinet	Our evaluation was on the maintenance and appropriate use of the signs. We used a focus group and a review of the inventory and maintenance history of the signs to recommend improvements.

Question 5. Does your agency have written guidelines or methodologies for evaluating effectiveness? Caltrans indicated yes. After an email follow-up, their guidelines are for operating procedures and installation.

5. Does your agency have written guidelines or methodologies for evaluating DMS effectiveness?	
Mark Demidovich Georgia DOT	No
Carlton Allen TxDOT Houston District	No
Jesus Leal TxDOT Pharr District	No
Elizabeth Ramirez City of Dallas	No
Charlie Cardenas TxDOT Corpus Christi District	No
Michael Floberg Kansas DOT	No
Kelly Damron North Carolina DOT	No
Navin Nageli Colorado DOT	No
Gary Thomas California DOT	Yes
Jeff Galas Illinois DOT	No
McCarthy K. Braxton Ohio DOT	No
Gene Glotzbach Florida DOT	No
Nancy Albright Kentucky Transportation Cabinet	No
Tai Nguyen TxDOT Fort Worth District	No
Edgar Fino TxDOT El Paso District	No

Question 6. Does your agency have different evaluation methodologies for the different types of messages?
Seven respondents indicated no.

6. Does your agency have different evaluation methodologies for the different types of DMS messages?	
Elizabeth Ramirez City of Dallas	No
Charlie Cardenas TxDOT Corpus Christi District	No
Navin Nageli Colorado DOT	No
Gary Thomas California DOT	Yes
Jeff Galas Illinois DOT	No
Gene Glotzbach Florida DOT	No
Tai Nguyen TxDOT Fort Worth District	No

Question 6a. If yes, please explain.
Caltrans indicated that they conduct visibility evaluation on different sign technologies.

6a. If yes, please explain.	
Gary Thomas California DOT	However, we do not conduct visibility evaluations on the different sign technologies.

Question 7. How were the guidelines or methodologies developed?
Caltrans indicated various personnel within the agency developed them, and the *Manual of Uniform Traffic Control Devices* was the primary reference.

7. How were the guidelines or methodologies developed?	
Gary Thomas California DOT	The guidelines were developed by a statewide taskforce that consisted of personnel from our transportation management centers, incident management teams, traffic operations, and Maintenance and Construction Divisions. The document provides guidance on operating procedures and installation. We use the *MUTCD* as our primary reference guide. Our goal is to provide Caltrans operators with a document that will assist them with reducing consistent messages that adhere to federal and Caltrans policy regarding CMSs.

Question 8. What data requirements does your agency have, if any, for the evaluation of DMS effectiveness?
Caltrans responded to this question; however, no detailed data requirements were given.

8. What data requirements does your agency have, if any, for the evaluation of DMS effectiveness?	
Gary Thomas California DOT	Our requirement is based on studies done 20 plus years ago. An overall deployment strategy was determined, which we still use today.

Question 9. Are the data readily available to support the evaluation of DMS effectiveness?
One respondent from TxDOT Fort Worth District responded yes. Three others said no.

9. Are the data readily available to support the evaluation of DMS effectiveness?	
Charlie Cardenas TxDOT Corpus Christi District	No
Navin Nageli Colorado DOT	No
Gary Thomas California DOT	No
Tai Nguyen TxDOT Fort Worth District	Yes

Question 10. In your opinion, what are the benefits of DMSs?
The majority indicated that communicating and providing important information related to the specific travel route is the major benefit (the benefit that drivers are able to decide on route travel). Two respondents indicated that Amber Alert is a benefit.

10. In your opinion, what are the benefits of DMSs?	
Mark Demidovich Georgia DOT	DMSs allow us (the DOT) to communicate important information to the motorists. In their standard mode (i.e., when not giving incident information), our signs give travel times to a major downstream point. This allows road users to effectively gauge the conditions of the freeway downstream of them. During incidents, we attempt to give the severity of the blockage so that motorists can decide to stay on the freeway, or divert.
Carlton Allen TxDOT Houston District	Information provided to drivers via DMSs is predominately real time and in vehicle. Provide in-vehicle information to drivers on roadway obstructions, such as incidents and construction. Pre-construction information can be targeted to users of the affected roadways. The variations of use are widely varied by need. Ultimately the major benefit is the ability to provide in-vehicle information to drivers after they have already begun their trip.
Jesus Leal TxDOT Pharr District	They can convey clear and timely information to the traveling public associated with incident management or traffic control during maintenance or construction activities.
Elizabeth Ramirez City of Dallas	Gives motorists information about the conditions of the roadway and an opportunity to use alternate roads or modes of transportation.
Charlie Cardenas TxDOT Corpus Christi District	Traffic control, emergency evacuation and information, and incident management.
Michael Floberg Kansas DOT	The benefits are really related to the traveler. The DMS provides information that is needed by the traveler to make an informed decision. That decision can relate to weather, incident, work zone, etc. The other benefit that we feel is important is AMBER Alerts. Getting this information to the public is vital to ensure the safe recovery of abducted children.
Kelly Damron North Carolina DOT	Best way we have of giving en route info to targeted audiences.
Navin Nageli Colorado DOT	Providing traveler information—construction, events, etc. Providing incident information—condition, alternate routes, etc. Assist in Amber Alert. Assist in speed enforcement—phone number posted to report aggressive driving. Assist in providing regulatory information—chain laws, HOV lanes.

Gary Thomas California DOT	They provide our motorists with timely, useful, accurate, and reliable information that is pertinent to their trip.
Jeff Galas Illinois DOT	DMSs are useful in displaying major incident information, severe lane reduction, and routine congestion reporting allowing the motorists to make informed decisions on their travel. The display of current information gives assurance that a situation is acknowledged and that something is being done to remedy the delay. The motorists of the Chicago area have come to expect the service provided, as well as expect more.
McCarthy K. Braxton Ohio DOT	Provides instant messages in real time.
Gene Glotzbach Florida DOT	It provides feedback to the public on road conditions that then allows the motorist to make a decision on whether to continue on the facility or seek an alternate route (detour). There is also some benefit to a motorist in just knowing what is going on. It provides a soothing effect that may reduce secondary incidents.
Nancy Albright Kentucky Transportation Cabinet	Effective for notification of violations of driver expectations.
Tai Nguyen TxDOT Fort Worth District	DMSs are the most effective ways to communicate real time to en-route drivers. Messages on DMSs can specifically convey traffic information that applies to the routes in front of them, and that can change dramatically during their drive time even between radio traffic reports.
Edgar Fino TxDOT El Paso District	Informing the traveling public what is ahead of them as they travel along the roadway at high speeds. Letting them know why their speeds have been reduced by congestion, incidents, or lane closures.

Question 11. How could these benefits be measured?
The majority of the respondents indicated that surveys are the best way to measure DMS benefits. Other suggestions included evaluating incidents, secondary incidents, and queue length.

11. How could these benefits be measured?	
Mark Demidovich Georgia DOT	Focus groups.
Carlton Allen TxDOT Houston District	Determining the number of drivers that actually read the DMSs. Determining the number of drivers that heed warnings of information provided, such as detouring around a road closure.
Jesus Leal TxDOT Pharr District	Reduced overall incidents or minimizing secondary incidents or chain reactions (multiple car pile-ups) as well as keeping maintenance and construction crews safe.
Elizabeth Ramirez City of Dallas	Percentage of vehicles that find the messages useful and defer to another route. Percentage of time sign is used.
Charlie Cardenas TxDOT Corpus Christi District	Measure traffic flow (speed) by means of detectors. Also, public opinion through surveys and media response.
Michael Floberg Kansas DOT	Surveys of the traveling public and the success rate of AMBER Alert.
Kelly Damron North Carolina DOT	Satisfaction surveys, diversion, etc.
Navin Nageli Colorado DOT	Conducting surveys that ask specific questions about DMS effectiveness. Conducting case studies of real events and incidents. Conducting modeling analysis.

Gary Thomas California DOT	Possibly through motorists (audience) surveys.
Jeff Galas Illinois DOT	When the service is not provided (due to communication or mechanical failure), we hear about it from the public. It is a desired service, even though we have no quantitative figures, only the qualitative response. Most motorists in the Chicago area are set on their routing, and diversion is the exception (except in extreme circumstances). We have had requests to extend the service (more signs) and provide additional information (currently, we display congestion from point A to point B, and have been asked to provide travel time calculation).
McCarthy K. Braxton Ohio DOT	Measure traffic volumes.
Gene Glotzbach Florida DOT	The number of incidents involving vehicles influenced by the congestion/incident. Also, the length of the traffic backup as well as the time it takes to clear the congestion.
Nancy Albright Kentucky Transportation Cabinet	Driver survey.
Tai Nguyen TxDOT Fort Worth District	Feedback, observation, or public surveys are usually how we measure success or failure.
Edgar Fino TxDOT El Paso District	By reviewing the crash information to find out if any secondary crashes have occurred to incidents.

Question 12. What are the challenges in evaluating DMS effectiveness?
Five respondents indicated that determining diversion routes taken by drivers due to the DMS messages is difficult. Also, receiving feedback from the public is a major challenge.

12. What are the challenges in evaluating DMS effectiveness?	
Mark Demidovich Georgia DOT	When motorists divert, you do not know if they diverted because of something they read on a DMS, heard on the radio, or otherwise. Crash reduction is very difficult to attribute to DMS messaging. Too many variables.
Carlton Allen TxDOT Houston District	Must conduct before-and-after studies. Making the determination of how many vehicles make detours based upon DMS recommendation would be difficult. It can be subjectively done through surveys or vehicle counts. Any surveys that are conducted must take into consideration the public's feelings and response to being observed for a study.
Jesus Leal TxDOT Pharr District	Assure that you get good reliable data that are timely and applicable to the specific location.
Elizabeth Ramirez City of Dallas	How can we inexpensively collect data on diversions? How does the diversion affect the efficiency of the surface streets? How did the total travel time on the diversion route compare to the incident-related delay time on the freeway route?
Charlie Cardenas TxDOT Corpus Christi District	Bad media or bad publicity may cause the traveling public to have a biased opinion on DMS effectiveness.
Michael Floberg Kansas DOT	Receiving feedback from the public. When everything is working and benefits the public, we usually don't hear from them. If something is not working, then we will hear. We have to proactively obtain the feedback from the public, good or bad.

Kelly Damron North Carolina DOT	How do you talk to the people that use them? How do you know that diversion was due to the sign? What if your sign doesn't suggest diversion; how do you measure success?
Navin Nageli Colorado DOT	Harder to quantify especially since DMSs are one element of providing information to the traveling public. There are others that are used such as HARs, local media, etc. Specific surveys are time consuming and expensive.
Gary Thomas California DOT	Collecting human behavior data; collecting motorist thoughts and concerns on what's the most effective way to operate a sign or display a message.
Jeff Galas Illinois DOT	We could use counts from our ramp detectors to evaluate the amount of traffic leaving the main lane, but this would probably be accurate only during an extreme blockage. The figures would be distorted by the number of motorists making the decision without the benefit of the signs. A motorist survey based on license plate could be used, but this is an expense not warranted with manpower and budget restraint. Visual monitoring of an incident response could be done, but once again if a motorist sees a government representative standing on the shoulder during an incident, it could result in negative impressions. If a camera is available in the vicinity of the sign, the reaction of motorists could be monitored, but cameras are not readily available at all reaction points.
McCarthy K. Braxton Ohio DOT	Too many variables.
Gene Glotzbach Florida DOT	Collecting the information.
Nancy Albright Kentucky Transportation Cabinet	Qualitative measurement. No consistency of messages from state or within states to help drivers interpret messages.
Tai Nguyen TxDOT Fort Worth District	It is very difficult to measure the benefits of the DMS messages. It is hard to read one's mind. If the message meets their personal plan of travel, then it is good; otherwise, it is bad. We can only expect the messages will serve a portion of total traffic.

SUMMARY

Through an agency survey and a review of relevant literature, current DMS applications and practices were assessed. Although underway, a national policy on DMS use and message design does not currently exist. Agencies are responsible for creating and establishing their own guidelines on DMS use, location, operation, and evaluation in their area. Without common guidelines, variations in the local policies are significant.

DMSs have been proven successful in disseminating a wide range of information to traveling motorists. The majority of respondents in the agency survey indicated that providing timely and important information related to the specific travel routes is a major benefit of DMSs. Although most DMS applications are considered effective, the appropriateness of several display policies is still being questioned. Concerns of information overload, adverse traffic impacts, and lost motorist confidence are prominent. On the other hand, practices concerning locating DMSs have scarcely been examined. Generally, DMS locations are established through prior experience with the local traffic problems. Only recently have researchers experimented with computer programs that can more precisely locate signs. These methods have not yet been implemented by any local traffic management agency responding to the survey.

Based on the responses of the agency survey and the results of the literature review, very little has been done regarding the evaluation of DMSs. DMS evaluations are generally conducted in conjunction with an entire ITS evaluation. While several metrics used to evaluate ITS are relevant to DMSs, special considerations should be taken due to the unique ability of DMSs to address random and unexpected events. The literature review found one example of performance metrics created specifically for DMS evaluation. These metrics addressed quantitative, as well as qualitative, issues, which are especially important in DMS evaluation. Fittingly, survey respondents suggest that user surveys would probably be the best way to evaluate DMS performance; however, they recognize that collecting these data is a major challenge. Other evaluation techniques suggested included evaluating the DMSs' impact on incidents, secondary incidents, vehicular diversion, and queue length. The agencies also established the following:

- The majority of agencies implement DMSs along with other ITS elements.
- Out of the 15 respondents, only three have completed an assessment of DMS performance without established agency guidelines. Two of these evaluations consisted of qualitative data (user surveys), and one evaluation consisted of quantitative data (traffic crashes).
- Caltrans was the only agency to report having DMS guidelines and an evaluation methodology in place. These guidelines focus generally on DMS operating procedures and maintenance.
- The TxDOT Fort Worth District was the only agency indicating they had data readily available to support DMS evaluation.

Even with an appropriate framework for evaluation, the issue of obtaining data still remains. If field data are not readily available, other means can be used to replicate the important inputs.

The literature review suggests that driving simulators and motorist surveys can be effective tools for gathering performance measures. A universal evaluation methodology focusing on appropriate metrics and data acquisition is necessary to effectively assess DMSs' impact on transportation systems. The issues of DMS message content, location, and evaluation must be addressed to aid in creating successful DMS systems.

CHAPTER 4: PRELIMINARY DMS PERFORMANCE EVALUATION METHODOLOGY

INTRODUCTION

Purposes and Uses of DMSs

DMSs have been recognized and implemented by agencies in Texas over the past two decades as a means of effectively communicating real-time traffic information to highway users. A major objective of instituting DMS systems along roadway corridors is to keep motorists aware of current and/or changing conditions resulting in delays and risks associated with collisions, stalled or disabled vehicles, adverse environmental effects, special events, or construction activities. The real-time capabilities of DMSs allow needed traffic information in response to these varying types of incidents to be quickly displayed.

DMS installations can provide warnings and advisories to motorists of congested roadways and can provide alternate route guidance leading to travel time reductions, increased speeds, and less delay. Route guidance information is particularly useful to through travelers on long trips or those confronted with several unfamiliar route choices.

Notifying drivers, as quickly as possible, of incidents or crashes ahead on a roadway is possibly the most important tool for effective incident management by giving motorists timely information, thereby creating the opportunity to divert to alternate routes. This may reduce delay and relieve congestion on the primary route experiencing the incident. Other types of “non-recurring” problems necessitating DMS advisement include adverse environmental effects such as rain, ice, snow, or fog that change pavement conditions and/or the visibility required for safe operations.

Roadwork, whether routine short-term maintenance activities or long-term major reconstruction, may temporarily cause delay and congestion problems that may be partially alleviated through either current or advance notice information displayed by DMSs. Real-time communication of both the presence and impact of construction and maintenance work zones is a common use of DMSs and has proven to be operationally beneficial. DMSs are also utilized to display information regarding routine road, ramp, lane, or shoulder closures. DMSs can provide alternate route guidance when a complete closure is required and detours are necessary, whether caused by construction maintenance or even in emergency situations.

In addition, DMSs can display travel and advisory information associated with recurring delay and congestion from everyday peak traffic demands and planned special events unrelated to a specific incident or situation. Driver reactions to congestion, including diversion to other alternate routes, are largely impacted by the information available to them to assess the extent of congestion ahead. Travel speeds and/or travel times are displayed by DMSs to convey the current extent of congestion. Qualitative information about the location, length, and degree of congestion may also be displayed by DMSs describing recurring roadway or operational situations. Special operational constraints can include directional lanes, tunnels, bridges, toll facilities, weigh stations, ferries, etc.

DMSs may also be used for other types of both traffic-related and non-traffic-related messages. Safety messages that are traffic related are considered appropriate public service announcements, which are very often displayed on DMSs. Most agencies require careful consideration of safety messages before they are posted on DMSs. Emergency and security information constitutes another type of public service announcement that may be displayed by DMSs.

AMBER Alerts represent a unique type of public service announcement with special requirements and provisions for DMS display. The purpose of these alerts is to advise individuals in the area of a child kidnapping crime and provide pertinent information for apprehension. Guidelines for DMS display address criteria for removing an AMBER Alert message if it creates an adverse traffic impact.

Other traffic-related public service announcements that are displayed on DMSs in some areas include air quality advisements and public law messages. The display of this type of information by DMSs is limited and only displayed when necessary.

Need for DMS Performance Evaluation

Currently, no national policies on the use or display of messages on DMSs exist. Agencies establish individual policies and guidelines through the recommended practices derived from current research and directives given by the *MUTCD*, which restrict use to displays of regulatory, warning, and guidance information related to traffic control.

Obviously, to perform acceptably, DMSs must be located to optimize exposure and allow or promote appropriate and timely motorist responses. It is also assumed, by design specification, that DMS facilities exhibit an information infrastructure capable of effective and efficient real-time communication of motorist information to satisfy each designated transmission purpose.

To establish the success of any DMS system in fulfilling its purpose or use, it is necessary to evaluate DMS performance. Evaluating DMS performance requires unique considerations not typically assessed for other, more traditional transportation improvement projects. Performance metrics for DMS evaluation may be categorized as either quantitative or qualitative depending on the type of motorist response to displayed information that is measured and the potential benefits resulting from that response.

POTENTIAL DMS BENEFITS

Background

Benefits achieved through the implementation and effective performance of DMSs are manifested in several different forms. These varying types of benefits from DMS utilization must be assessed and compiled to establish the absolute and relative value of DMSs in terms of mobility, safety, and user satisfaction.

Three methods are typically employed to analyze and evaluate any ITS improvement, including DMSs. These include benefit-cost analysis, impact analysis, and cost-effectiveness analysis. The most common of these evaluation approaches is benefit-cost analysis. This method weighs the costs of a project against benefits achieved resulting in an assessment of DMS installations that yield the greatest net social economic benefit.

Cost-effectiveness analysis does not determine the net social benefit but compares individual DMS projects based on their cost-efficiency. Impact analysis focuses entirely on the benefits of a DMS project with no regard to costs. Limiting factors to all three approaches are (1) the need for quantitative benefit data and (2) assigning value to qualitative benefits.

Qualitative Benefit Measures

Public acceptance and satisfaction with DMS operations is critical to successful performance. The location of DMSs and the message display format must be perceived as acceptable from the standpoint of sufficient visibility, legibility, and presentation to allow an appropriate and timely response. Messages displayed must satisfy motorists' expectations and needs for information that is useful/meaningful, accurate, reliable, and timely for the indicated advisement. Fulfillment of these information requirements with DMSs will optimize performance by influencing driver decisions and affecting behavior and response.

Quantitative Benefit Measures

The actual driver responses to displayed DMS real-time information may be measured quantitatively to assess both mobility and safety benefits. DMS performance as a result of timely and appropriate driver responses may improve mobility on a roadway or corridor by reducing delay as measured by shorter queues, less average delay per vehicle, shorter travel times for a given trip length, and reduced total vehicle delay. Effective DMS performance will influence or generate motorist diversion from an impacted roadway, thus reducing vehicle demands for available capacity and distributing traffic on alternate routes.

Mobility benefits of effective DMS performance may also be quantitatively established through higher measured travel speeds and increased facility through-put at bottlenecks to improve level of service (LOS). Efficient DMS communication can improve overall traffic flow and maintain beneficial volume-to-capacity (V/C) ratios. Time of incident-related capacity restrictions can also be minimized.

Along with mobility benefits, or as an independent quantitative measure, safety may be improved through positive DMS performance. Displayed advisories of incidents, road conditions, work zones, or adverse environments ahead that are designed to promote increased caution or to induce speed or travel path adjustments may prevent or reduce traffic crashes or the severity of collisions. Crashes that do occur may be less severe due to slower vehicle approach speeds or avoidance maneuvers made as a consequence of responses to properly located and timely DMS-displayed information. Significant crash cost savings may be attributed to the reduction in crashes (positive safety benefits) resulting from DMS performance relative to that when no real-time motorist communication is available.

Figure 1 provides a summary framework of potential DMS performance metrics utilized in the evaluation of benefits attributable to DMS installation. These performance metrics are segregated by the type of data employed in the analysis—quantitative or qualitative.

Depending upon the time of assessment, pre- (before) or post- (after) DMS implementation, and/or the environment of DMS installation, urban or rural, any or all of these performance metrics may be used to analyze benefits.

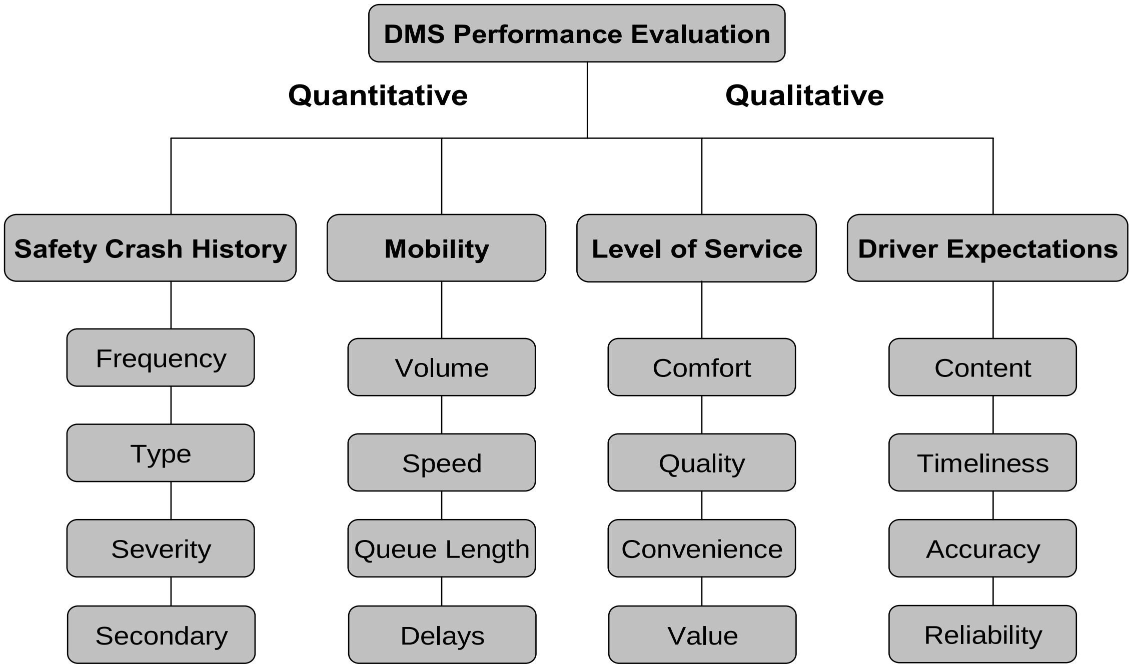


Figure 1. Summary of DMS Performance Metrics.

TYPES OF ANALYSIS

Overview

Various types of benefit analyses may be employed for evaluation of DMS performance. The selection or application of a given analysis technique depends upon both the functional time frame of analysis, either in planning or operational phases, and on the environment of DMS implementation, either urban or rural.

Benefit analysis applied in planning, or before DMS installation, may be used for several purposes: first, to establish baseline data conditions, using either qualitative or quantitative data, for subsequent post-implementation comparisons; second, to assess potential DMS benefits in justification of investment expenditures; and third, to optimize the location of DMSs along a route or corridor based on maximizing benefits. Benefit analysis used in planning to optimize DMS locations follows two methods—genetic algorithms and integer programming. Each method has extensive data requirements that limit their application.

Genetic algorithms give several solutions, not just one "best" solution. The constraints required in genetic algorithms are less than those necessary to find an integer programming solution. To determine the optimal DMS location, the benefits of DMSs must be evaluated at all possible locations. Potential benefits of DMSs are defined at a diversion point as the sum of the reduction in delay and accidents on the freeway upstream of an incident. These benefits are maximized through a computer program written to apply genetic algorithms to optimized DMS locations. This program optimizes DMS locations, calculates the total adjusted benefits, and determines the installation order of DMSs. DMS locations with the highest benefits are recommended first for installation. If the number to install is not predetermined, the genetic-algorithm program recommends a maximum number of DMSs. This is done through the calculation of benefit-cost ratios for each quantity of DMSs at the optimal locations. The research team does not recommend installing a quantity of DMSs that produces a benefit-cost ratio less than one. This methodology accurately determines the optimal locations and quantities to be installed on a traffic network. It is important to note that the application of this methodology requires knowledge of the origin-destination trip matrix on a freeway, the characteristics of the freeway incidents, and an expected diversion response rate to DMSs located at decision points.

Integer programming may also be used to optimize DMS locations in planning. With a given number of sign installations, possible locations can be determined and analyzed. Optimal locations are chosen so that the long-run expectation of benefits is satisfied under stochastically occurring incident scenarios. The main benefit of correctly locating DMSs is the reduction in total user travel time. Implementation of the programming requires numerous inputs that describe the geometry and traffic patterns of the highway network to be analyzed. Additionally, compliance to DMSs is taken as an external parameter that must be assumed for evaluation purposes. The problem is simulated using a dynamic traffic assignment algorithm that aides in determining the effectiveness of DMS locations. It is necessary that each location has a high probability of capturing the randomly occurring incidents and can then effectively divert traffic. The final solution generated by the integer-programming model determines the optimal location for all incident scenarios on the system. The solution may not be optimal for an individual incident.

For operational purposes, preferably, both pre-installation and post-installation data are assimilated to allow comparative assessment of the DMS implementation effect through benefit analysis. However, realistically, many DMS installations were incorporated in conjunction with other construction projects without forethought to obtain pre-installation quantitative or qualitative data. Many times, for these locations, only crash history can be obtained to assess pre- versus post-installation safety benefits. Therefore, whether for planning or operational purposes, time of assessment (i.e., pre- or post-installation) is a critical factor limiting the extent of DMS performance evaluation with benefit analysis.

The focus and extended potential of any benefit analysis for DMS performance evaluations depend also upon the environment of implementation, either urban or rural. Resources, equipment, and capabilities for data collection and directed benefits vary between a DMS implementation along an urban route or corridor versus that along a rural roadway. Application of DMS communication in urban highway environments emphasizes primary utility for sustainable mobility. Communications center on incident notifications to allow diversion for delay reduction. Monitoring of operations and traffic management strategies is much more sophisticated than in rural highway environments. Applications of DMS systems in rural highway environments do not necessarily address congestion issues but are instituted to improve safety through warning communications of adverse weather, incidents, or construction.

Qualitative Benefit Analysis

Qualitative benefit analyses are directed to establishing DMS influence on driver decisions (and ultimately their quantifiable responses) and motorist opinions about the worth or value of DMS communications. These types of analyses obtain information through motorist behavioral studies that include collecting user panel trip diaries, collecting information elicited from focus groups, or conducting surveys, including attitudinal, opinion, and stated preference approaches.

User groups or panels represent one technique of data collection for qualitative benefit analyses. Individuals are requested to keep detailed travel logs of their routing decisions correlated with exposure to DMS communications of incidents, construction, and/or delay. Opinions, reactions, and reported behavioral responses are all noted by route location and time.

Another approach to qualitative benefit analysis is to obtain information from focus groups. It should be noted that the term “focus group” is short for “focus group interview.” To function best, planners of these groups need to attend to all three concepts. This technique, as contrasted with both other group processes and other interview approaches, should be limited to a small set of issues that can, in part because of its focused scope, be explored in some depth. As a group process, the focus group is directed toward encouraging among its participants interaction and discussion that have the potential for eliciting information that is more than a simple summation of individual participants’ contributions. As an interview, the group is not a completely free-wheeling, undirected process. Rather, it is directed by a moderator whose job is to promote interaction and genuine discussion and to make certain that the group remains on the specific topics of interest while still providing an atmosphere conducive to an uninhibited and full exchange of views and information.

In addition to providing a means for getting information about participants’ familiarity and/or reaction to, for example, existing or future DMS design and operations characteristics, focus groups provide an opportunity to obtain information about attitudes and opinions in greater depth than typically possible in questionnaire-based surveys. The interactive nature of these group discussions allows probing and follow-up by the moderator (and other group members) to clarify and expand upon participants' responses.

Within the context of DMS evaluations, focus groups are particularly well suited for:

- identifying and clarifying the needs of specific groups of drivers,
- identifying what drivers know or do not know about DMSs in general and specific DMS applications,
- identifying problems in project implementation,
- providing information that can assist in survey instrument development,
- assisting with interpretation of previously collected quantitative findings from operational data and information from prior survey data, and
- generating new ideas.

Among the advantages of focus groups over other methods are:

- opportunity to obtain in-depth insight;
- more cost-effective than individual interviews;
- findings, typically presented in narrative form, allow the use of direct participant quotations that can serve to exemplify and make clear individual and group responses; and
- participants are free to volunteer information on important points that the evaluation may not have considered previously.

Disadvantages encountered with these groups include:

- Open-ended questions and responses can make summary and interpretation difficult and time consuming.
- Participants may not be willing to express some concerns in a group setting depending on the moderator or other participants.
- The moderator must have sufficient skill and experience to avoid biasing participant responses as a function of the interaction between himself or herself and participants.

- The small number of participants and typical lack of random selection limit the ability to generalize to a larger population. Focus groups are *not* appropriate for quantifying information, e.g., specifying what proportion of older drivers believes that DMSs are or are not very useful.
- Great care must be exercised in the analysis and reporting of focus groups to avoid reflecting the biases of the analyst.

Questionnaire-based survey instruments, either self-administered or administered via telephone or in-person interviews that are developed to elicit qualitative and quantitative data from users and potential users of facilities with existing or proposed DMSs can, if well designed and implemented, enhance or replace group interviews as a means for getting DMS evaluation information from drivers. Unlike focus groups, survey data can be used to make valid statistical statements and, with appropriate sampling and statistical procedures, can be generalized beyond the sample of respondents to the larger population.

Surveys used to support DMS evaluation can cover a broad range of issues and specific questions dealing with driver attitudes, familiarity with and knowledge about DMS issues and operations, and preferences for specific DMS attributes. They can be administered by mail, as household or business drop-off surveys, over the Internet as web-based surveys, or through telephone contact.

Within the context of DMS performance evaluation, a survey, usually some form of questionnaire instrument, used for qualitative benefit analysis, can be developed to obtain a wealth of information, including:

- types of vehicle driven, e.g., passenger vehicle or commercial truck;
- driving experience, e.g., by age or number of years with a valid driving license;
- frequency of driving on the DMS route, e.g., daily, weekly, or monthly;
- experience with DMS systems, i.e., the extent to which DMSs have been viewed or utilized;
- understanding of DMSs' purpose, i.e., real-time motorist communication;
- expectations of displayed information, including content, display format, or location;

- satisfaction with DMS displays in terms of perceptions of content, format, timeliness, accuracy, reliability, usefulness, or criticality;
- importance of information currently or planned to be displayed, e.g., weather, pavement condition, construction, accident, special event, etc.;
- reported response to displayed DMS information, e.g., are they ignored, promote greater awareness/alertness, increase motorist caution, speed adjustment, diversion, etc.;
- detail of information displayed, e.g., delay, diversion, or incident location;
- factors influencing perceived DMS usefulness, e.g., timeliness, accuracy, or reliability;
- evaluation of operational performance, e.g., are DMSs perceived as adequate, inadequate, or in need of change;
- assessment of DMS benefits, in terms of utility, safety, or mobility; and
- opinions regarding DMS expenditure justifications.

Among the advantages of questionnaire-based surveys over focus groups or other interview methods are:

- Administration is less time consuming for individual respondents than focus groups.
- Surveys can be anonymous.
- Surveys can be more economical per respondent than group interviews.
- Survey results are much more amenable to generalization.

Disadvantages encountered with these questionnaires include:

- There are no means for probing, clarifying, or following up on respondents' answers.
- Respondents must be motivated to complete the survey—low response rates can be a problem.
- If open-ended questions are employed, large sample sizes can make analysis time consuming and expensive.

Quantitative Benefit Analysis

Quantitative benefit analysis addresses direct measurements of DMS impact on both mobility and safety along a given route, network, or corridor of implementation. Comparisons are made between pre-installation conditions and post-installation conditions to establish mobility and safety benefits demonstrated through congestion/delay and crash reductions and associated cost savings.

This “before-after” comparative analysis is predicated upon the availability of required data prior to DMS installation. At most locations, this is not a problem for safety benefit analysis, although the delays between crash occurrence and the availability of the crash data for analysis purposes has been problematic (this problem should be reduced significantly with the implementation of the new crash reporting information system [CRIS] within the state).

Safety Benefit Analysis

A before-after safety benefit analysis involves a comparison of vehicle crashes along a roadway or within a highway corridor prior to the installation of a DMS system for real-time motorist communication to those crashes experienced on the same facility after DMS system installation. Conceivably, more effective, timely advisement of weather changes, pavement conditions, construction and/or incidents will allow motorists to heighten attention and alertness, exercise increased caution, adjust driving behavior, and avoid or reduce the number and severity of crashes.

This crash comparison should desirably be made within a minimum of 3 years of pre-post installation crashes. Crashes of significance for comparison are those defined as “preventable” or “susceptible to correction” that have no adverse driver behavior involved; i.e., alcohol, excessive speed, reckless driving, no license, etc.

Before-after DMS installation comparisons should include not only total crash frequency for a given roadway section length (miles), but also incorporate VMT for the period of analysis, thus allowing calculation of crash rates. This, then, will allow an assessment of safety relative to other similar functionally classified facilities.

Crashes should also be analyzed by type including vehicle involvement (commercial trucks), manner of collision (right angle, rear end, or sideswipe), pavement condition (dry, wet, ice, or snow), and time of collision (day or night). DMS performance may prove to be highly effective under a given set of conditions to affect certain types of crashes, while proving ineffective under different scenarios with no significant impact in reducing other types of collisions.

Comparative crash history should also be segregated to represent severity associated with analysis collisions. Crashes should be categorized by number of fatalities (K), incapacitating injuries (type A), capacitating injuries (type B), and possible injury (type C).

Mobility Benefit Analysis

Developing "matched" pre- and post-DMS installation data for mobility benefit analyses is much more difficult. From a mobility assessment standpoint, it would be desirable to quantify volumes, speed, delay, queue lengths, and diversion along a potential roadway under consideration for DMS implementation. Such pre-installation documentation of both recurring and incident operations would allow comparisons to post-installation operations with DMS communications to establish mobility benefits from reduced delay.

In reality, most rural districts do not have the resources (detection equipment) in place to collect these data in either a before or after implementation condition. Some anecdotal information may be available or possible to produce from known incidents. However, unless recognized and accounted for early in the planning for a rural DMS system corridor, the capacity to collect the necessary data to establish mobility benefits does not exist.

Even in urban districts, which have the technology capabilities to measure the stated traffic operational parameters, many DMS installations were implemented randomly by site location or route as addenda to freeway reconstruction or rehabilitation projects. Because signs were installed but left blank for extended periods, were made operational but experienced major maintenance problems for extended periods, and/or were made operational under designated operational formats that changed significantly over time, true-matched before-after comparisons are difficult to conduct.

Other difficulties are manifested in measuring true mobility benefit indicators that can be fiscally accounted for. For example, queue lengths can be correlated with vehicle delay and valued, but unless all traffic volume is measured in and out of a given incident queue over time, a complete assessment cannot be made. In an analysis of input-output volumes along a facility with DMS communication, it is difficult to establish the differences in approach volumes that are the result of DMS influence as opposed to other factors that cannot be accounted for; i.e. lower traffic due to public radio advisories, etc.

As a result of these difficulties, roadway/traffic simulation models seem to offer a viable means to isolate DMS mobility benefits, while maintaining control of other influencing variables. In fact, a properly calibrated traffic simulation model may be the only means of reliably estimating the effect of DMS messages on traffic operations on the entire freeway arterial network. Also, the run time required for simulating multiple scenarios (e.g., combinations of different traffic demands, incident durations, and variations in traffic control strategies) is much shorter than the time required for the field observation of a single event. Simulation analysis, however, does require some detail of a prior knowledge or reliable estimates of motorist response to DMS communication. Furthermore, simulation models are still deficient in terms of adequately capturing the dynamic diversion decision-making processes that occur in a transportation network. Consequently, the percentage of motorist diversion or expected speed reduction response must be explicitly accounted for by the analyst during the simulation process in order to achieve reasonable calculations of effects.

Output from before-after comparative mobility benefit analyses includes totals for reduction in delay and travel time with associated costs, reduction in queue length and queue, and reduction in fuel consumption/air emissions with associated costs. While delay, travel time, and queue length measurements are difficult under the best conditions, with proper diversion estimates and calibration, these parameters may be obtained through simulation.

Figures 2 and 3 illustrate both quantitative and qualitative DMS benefits as distributed between safety and mobility as well as differences between urban and rural environments of installation. Performance metrics used in analyzing benefits are categorized into groups on these graphs as each influences driver decisions for diversion.

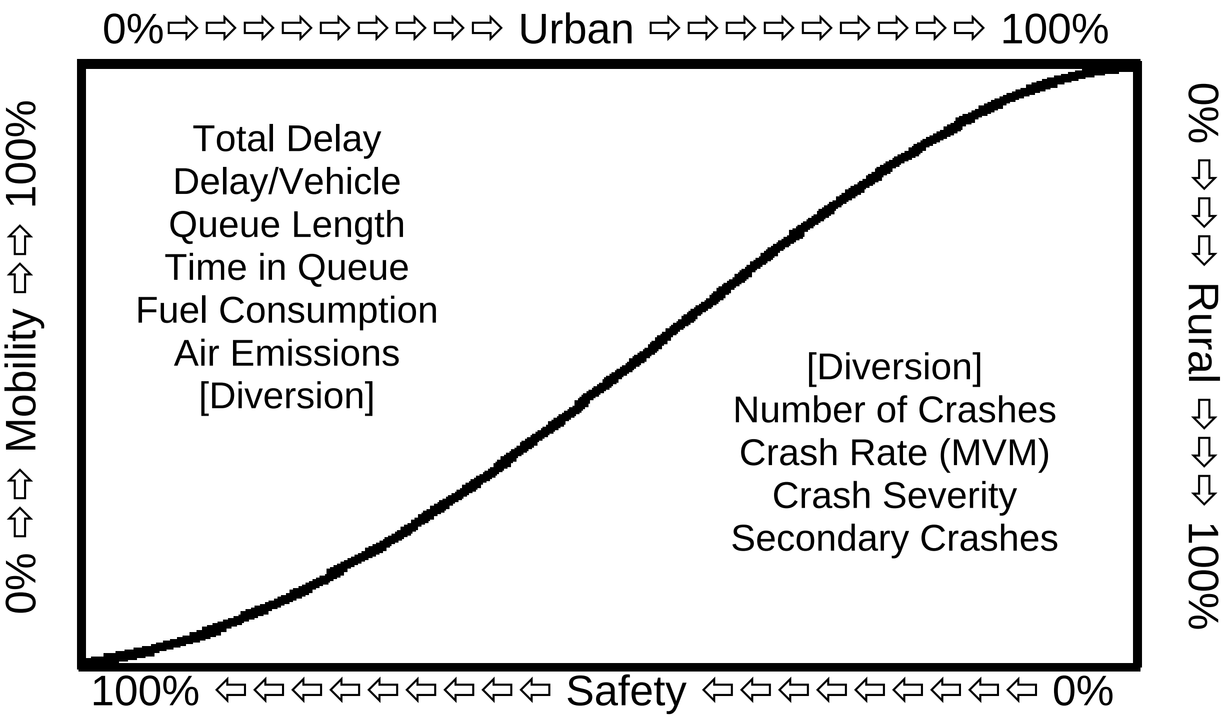


Figure 2. DMS Benefits—Quantitative.

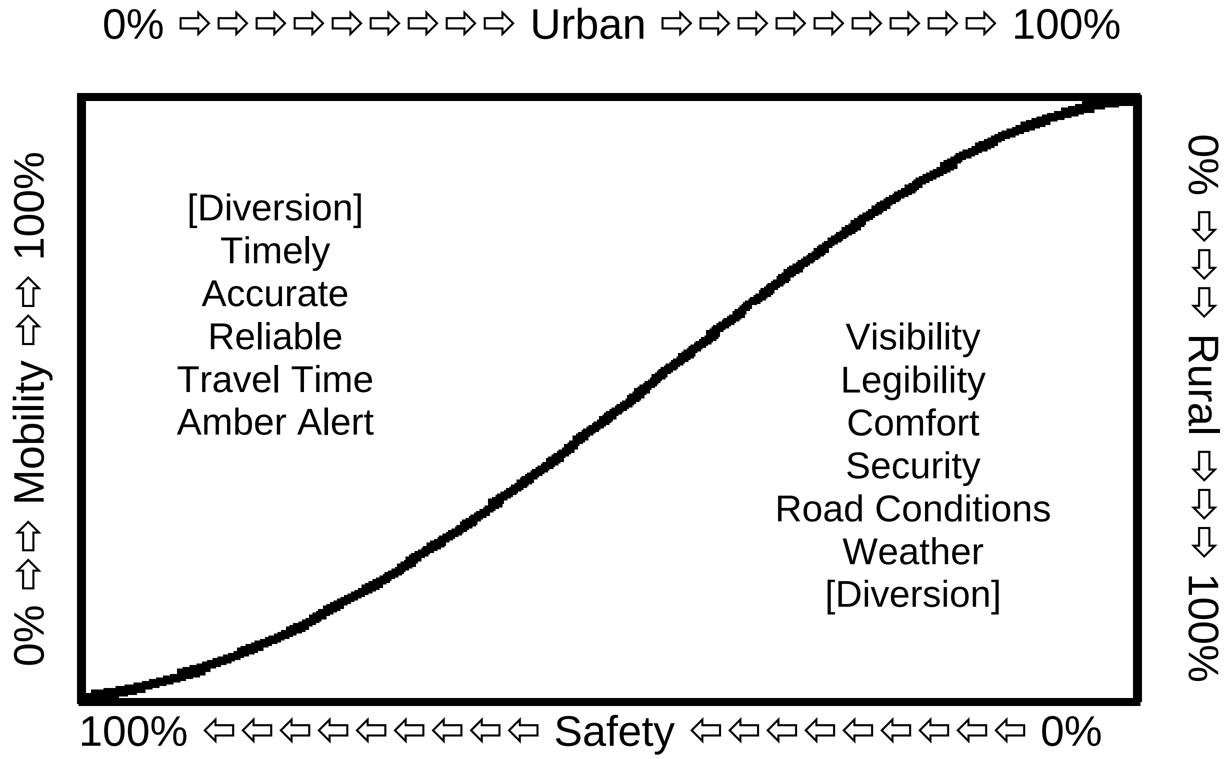


Figure 3. DMS Benefits—Qualitative.

QUALITATIVE DMS EVALUATION METHODOLOGY

As previously noted, measures of DMS users' (i.e., motorists') qualitative evaluations of DMSs, based on their perceptions, opinions, attitudes, and reported experience with DMSs, can be obtained through user panel trip diaries, focus groups, and user surveys. The purpose of this section, therefore, is to provide an overview of some of the important considerations relevant to the collection and use of qualitative data in the evaluation of DMSs that will assist those charged with conducting such evaluations in making choices that may best serve the overall evaluation goals and to provide guidance pertinent to qualitative data collection for DMS evaluations.

Selection of the appropriate methodology used for obtaining qualitative measures of DMS performance varies as a function of the goals and objectives of a particular evaluation. Although very similar information can be obtained by means of panel diaries, focus groups, and surveys, these approaches differ in the extent to which the information they provide can be generalized to the broader population of motorists that they sample. Typically, information developed from well-designed surveys based on a probability sample of the driver population of interest will allow much greater generalization than either focus groups or user panel diaries. This significant advantage of survey methodologies, however, must be weighed against other evaluation considerations, including technical issues pertaining to obtaining a probabilistic sample, resources available to the evaluation (both fiscal and time), and the specific use that will be made of the qualitative data that will be collected. Addressed here are some of the significant issues that need to be resolved when planning and implementing qualitative data collection efforts, specifically by means of focus groups and user surveys.

Taken together, the advantages and disadvantages of focus groups suggest that the most appropriate use of focus groups in DMS evaluations are in cases in which preliminary information is needed to assist in identifying broad issues or problems that will be addressed further in (e.g., used previously) user surveys; for clarifying or exploring in greater depth user responses obtained by other means (e.g., diaries or previous surveys); or other instances for which either generalization to the wider driver population is either not required or is premature. As a rule, focus groups will be of significantly greater value earlier in the planning and implementation phases of DMSs rather than in post-operational phases and for evaluation of new or unique features of DMSs for which the potential range of driver understanding, acceptance, and likely responses to DMSs exhibiting these unique features may be unclear.

Methodological Issues and Guidance for Conducting Focus Groups

Although there is a range of opinion among professional practitioners as to the ideal characteristics of focus groups and each focus group has distinctive qualities that make it unique, a general consensus on many of the important facets of group planning and implementation can be suggested as well as some of the pitfalls to avoid. In those instances in which focus groups are deemed appropriate, a number of guidelines, discussed below, can assist in maximizing the usefulness of the groups to the evaluation. What follows is by no means a comprehensive guide for the planning and conduct of focus groups but rather a selective set of issues about which DMS evaluators should be aware and consider when using this qualitative approach.

Participant Selection

Except under very special conditions, not typically met in most focus groups, statistical sampling of a defined population (e.g., all drivers who have been exposed to a specific DMS on a particular highway segment) is neither required nor attainable. Nonetheless, it is advantageous to identify and recruit potential group participants who incorporate as many of the most salient characteristics relevant to the issue at hand as possible. An issue affecting participant selection, on which focus group experts disagree, relates to the degree of homogeneity/heterogeneity exhibited by participants in a single group. Too much similarity among group members can limit useful interaction that arises from differing experiences and backgrounds of heterogeneous groups. On the other hand, in many groups highly dissimilar participants may lack sufficient common ground to interact successfully. These issues present more of a problem for groups in which very sensitive topics are the focus. While planners should be aware of potential areas in which heterogeneous groups may hinder discussion, this is less of a concern with the relatively uncontroversial driver and roadway issues related to DMSs.

Number of Groups

It is preferable to conduct at least two focus groups for each sub-group of interest to the evaluation. The problem comes in deciding what the relevant sub-groups are. This issue is closely related to that of determining the best balance between homogeneous and heterogeneous groups. For DMS issues, segregating groups by gender, ethnicity, or socioeconomic status is probably not necessary. Greater consideration should be given to having separate groups for commuters and non-commuters, and younger (perhaps less than 25 years old), 25- to 60-year-olds, and older drivers (>60 years old).

Group Size

As with most advice regarding focus groups, group size recommendations are not cast in stone. Depending on specific circumstances, smaller or larger groups than are generally recommended may be appropriate. That said, groups of 6 to 12 participants are considered by many practitioners to be the lower and upper bounds for successful focus groups. Fewer participants likely require that more groups be conducted in order to approach a representative range of respondents' responses and are less cost-effective. In small groups, participants also tend to interact somewhat less. The group interview can easily devolve into what are essentially individual interviews with multiple observers. Larger groups present the likelihood that some participants will not have the opportunity to make their views known, and/or the in-depth and interactive features, which are important to successful groups, will be limited. The larger the group, the more likely that there will be less group cohesion and the development of isolated and, in some cases, competing sub-groups. Our preference for most groups, including those discussing DMS issues, falls in the 8 to 10 participant range.

Group Setting and Logistics

Although many of the details of planning and implementing focus groups appear to be of little consequence compared to the larger issues of DMS evaluation, it needs to be recognized that the group dynamics and ultimately the quality of information obtained can be significantly influenced by such apparently trivial considerations as the characteristics of the venue where groups are held, the spatial arrangements of the room, the presence of group observers, and the general tone and ambiance of the group setting. It is not necessary to hold focus groups in facilities specially designed for that purpose, but it is important to select venues and follow procedures that will provide a comfortable, distraction-free environment that promotes group interaction. Groups are best held in rooms of sufficient size to be neither physically confining nor psychologically invasive regarding personal space with participants and the focus group moderator arranged around a table such that all participants can see each one another, e.g., in a circle. This will serve both to facilitate interaction and lessen the likelihood that particular members will dominate the group. As a rule, it is best to limit attendance at group sessions to the actual participants, the group moderator, and a note taker/technician. If observers are present, they should be small in number and physically separate from the group itself. Observers should be treated very much like any recording equipment used in the group, i.e., their presence should be acknowledged at the beginning of the session, after which they should be as quiet and unobtrusive as possible. With rare exceptions, groups should not exceed 2 hours in duration. In our experience, 60 to 90 minutes usually works best. A thoughtfully prepared moderator guide implemented by an equally well-prepared moderator (see below) can assist in making the most of the limited time during which most groups remain productive and facilitate allowing the group to go where the discussion takes it without losing sight of its purpose.

Moderator Characteristics

A critical factor to the success of a focus group is the moderator. The moderator is the discussion leader and facilitator of the group. Often in addition to conducting the groups, the moderator will also be an active participant in other aspects of the evaluation, including preparation of the group guide or interview outline and analysis and reporting of the group findings. There are some advantages to using professional moderators, but while significant experience in group settings is clearly an advantage, professional moderators are not a requirement. Similarly, the moderator is not required to be a technical expert in the subject matter at hand. Broad familiarity, but not necessarily expertise, in the systems being evaluated is important, but technical expertise and, especially, participant-perceived vested interest in the specific DMS and roadway facilities being examined tend to restrain group participants from expressing their true opinions, beliefs, etc., from a fear of looking foolish or ignorant to an “expert” or “authority figure” or, worse, may suggest to group participants that the moderator has a specific agenda he or she is trying to validate. Without regard to the level of expertise or personal views of the moderator, he or she must not allow those views or that expertise to influence the group beyond providing pertinent information.

Obviously, a good moderator must be a good listener, have a dynamic but not overpowering personality, and be perceived by group participants to be interested in both his/her work and the importance of each participant's contribution. The moderator must be capable of responding to participants' non-verbal as well as verbal responses and recognize that the group will respond to his or her non-verbal cues as well. The moderator needs to be able to probe for additional information and clarification from group participants without implying that their original responses are deficient or wrong. The moderator needs to be able to blend in with the group and simultaneously remain in control of the discussion. The moderator's job is, initially, to establish a non-threatening, non-evaluative atmosphere in which participants feel unrestrained from expressing themselves honestly and without concern about whether they may agree or disagree with other group members. Having established this type of environment, the moderator's job becomes one of keeping the discussion on track and assuring the active involvement of all of the group's participants.

Moderator Guide

An essential element in the planning for successful focus groups is the development of a moderator guide that will provide some structure and assist the moderator in conducting the group discussion. Two general formats of moderator guides can be distinguished—the topic guide and the question guide. As implied by their names, the former consists of a general outline of topics or issues to be addressed in the group. It is essentially a list of phrases or words to remind the moderator of issues to be pursued and the general order in which to pursue them. The "question guide" is a much more complete sequence of specific questions written in a conversational style. While either approach (or a combination) can be used successfully, researchers recommend the latter, especially for less experienced moderators and for situations in which multiple groups will be conducted by different moderators.

Regardless of the specific format of the moderator guide, it should include, generally in sequence, the following:

- a welcome and introductory section designed to familiarize participants with the focus group process and the mechanics of participation (e.g., informed consent, compensation, disclosure of recording devices, etc.) and the purpose of the research;

- participant and moderator introductions and ice breaking;
- background information for the participants;
- general questions;
- specific questions; and
- closing remarks and summary.

For both general and specific questions, positively framed questions should precede negative questions, and un-cued questions (i.e., without predetermined response categories) should come before cued questions.

In addition to providing the moderator with a detailed outline of the content of the group and specific questions to be covered, the guide should allocate projected time constraints for each portion of the group discussion and specify the use of any props or aids to facilitate the discussion. For DMS evaluations, simple maps and photographs of particular DMSs can be especially useful.

Data Reduction and Analysis

Just as a variety of analytic approaches are available for quantitative data, so too are the qualitative data obtained from focus groups amenable to a range of analysis methods. These include rigorous, technically sophisticated computer-assisted content analyses of various types. Such tools for analysis of DMS-related focus groups are not likely to be necessary. The raw data for the analysis, however, are essentially the same, i.e., the actual words spoken by the participants as captured via audiotaping of the proceedings. Transcription of the audiotape can be viewed as the first step in reducing the raw data to a useable form. Although some focus group practitioners analyze directly from the audiotapes, researchers recommend transcribing the recordings, with additional annotation based on listening to the audio (important emphasis on particular words that may be lost in a printed transcript can be recovered by listening to the audio) and non-verbal indications recorded by the note taker and moderator. The analysis for DMS focus groups is primarily descriptive in nature and usually not sufficient for providing statistically reliable numerical data. Nonetheless, compilations of the frequency of, for example, favorable (or unfavorable) opinions about specific DMSs, the number or proportion of participants who express similar problems with specific DMSs, or the consistency (or lack thereof) of reported diversion responses to specific DMSs, etc. are appropriate for inclusion in the analysis. It is usually *not* appropriate, however, to report these compilations as specific numbers that imply credence beyond the group to the wider driver population. At best, these numeric counts can be reported in somewhat non-specific general terms such as “some,” “most,” or “a preponderance” of participants. As noted previously, the extent to which such data can legitimately be generalized to the wider population is at most limited and usually unknown with any certainty. Consensus on particular issues, or lack of consensus, is useful to the analysis but must be interpreted cautiously.

Methodological Issues and Guidance for Conducting Surveys

As with focus groups, professional practitioners do not agree on all aspects of what constitutes the ideal characteristics of surveys. As was true for the group interview technique discussed previously, each survey also has distinctive qualities that make it unique. Nonetheless, substantial consensus on many of the important facets of survey planning and implementation does exist that can assist the DMS evaluator. This section will touch, very briefly, on some of these as they apply to surveys in general.

Large-scale surveys of the types anticipated for DMS evaluations may well require the assistance of a professional survey organization to adequately address at least some of the requirements for a probability-based survey. This is especially the case for developing an appropriate sampling plan that will meet the critical need to develop data that can be generalized beyond the respondent sample itself.

Sampling Issues

Even with the assistance of sampling expertise, the DMS evaluator must be cognizant of certain issues related to selecting a survey sample, many of which center on defining and then identifying the target population for the survey. Typical candidates include regular local peak travel time commuters, out-of-area travelers, and local infrequent and/or non-peak users of the roadways subject to evaluation. Technically, potential survey respondents should be selected from a specified sampling frame that constitutes the target population. The sampling frame essentially comprises a list of all potential respondents. A probabilistic sample of potential respondents is, ideally, selected from the sample frame through simple random, systematic random, or stratified random sampling procedures. Non-probabilistic sampling approaches, either quota sampling or convenience sampling, should be avoided.

Designing Survey Instruments

The design of survey instruments encompasses both the physical design and formatting of the instrument and the content of the survey. The design process includes identifying and writing the questions needed to meet the objectives of the survey, testing those questions to assure they are asked and answered as planned, and putting them into a format that maximizes the ease with which survey respondents (and interviewers in the case of instruments that are not self-administered) can complete the instrument.

Numerous published sources are available that can assist the evaluator in writing good survey questions. The care and skill used in constructing the questions asked have a direct impact on the validity and reliability of the survey and on the willingness of respondents to participate in the survey. No attempt is made here to offer comprehensive or specific survey design guidance beyond the very basic recommendations applicable to large-scale DMS surveys provided below:

- Avoid open-ended questions, especially in self-administered questionnaires. The potential benefit to be gained from the additional insight or provision of information not previously considered that is possible in open-ended responses does not justify the additional coding, interpretation, and analysis effort and costs.
- Do use closed-ended questions in which the respondent selects an answer from provided options, e.g., forced-choice or multiple-choice questions and items that include Likert-type scales. These types of items are both more efficient and more reliable in that all responses are provided from the same set of options. When constructing closed-ended items, the response categories should be exhaustive, i.e., they should include the full range of possible responses, preferably without resorting to options like “other.” Except in rare instances where multiple answers are desired, the response categories provided should be mutually exclusive. Standard, commonly used measurement dimensions are

readily available for use in questions measuring frequency, quantity, satisfaction, and priorities, and for rating agreement and answering evaluative questions.

Selecting a Survey Approach

There is no generic "best" survey type for obtaining qualitative information about DMSs. Each technique has inherent strengths and weaknesses. Summarized below are a few of the advantages and limiting factors of the most common approaches.

Mailed Surveys

Overall, mail surveys may provide the best option for most DMS evaluations requiring relatively large-scale survey efforts to obtain qualitative data, particularly because large geographic areas and large sample sizes can be accommodated relatively economically. However, potential respondents need to be motivated to complete and return the surveys. As survey length and complexity increase, response rates are likely to decrease. Even with short and straightforward mail survey instruments, follow-up mailings and/or incentives to complete the survey may be necessary to assure acceptable response rates. Up-to-date address lists can be difficult to obtain for the selected sampling frame. Also, respondent questions or confusion cannot be readily addressed.

Field Surveys

Field surveys, including household or business drop-off surveys that are mailed back after completion, can produce higher response rates as a function of the personal contact that may be initiated at drop-off. Such contact also provides the opportunity for at least limited personalized explanations of the purpose of the survey. With sufficient preplanning, drop-offs at businesses, especially large employers with numerous commuting employees, have the potential for good return rates and can resolve many of the difficulties in identifying respondents within the desired sampling frame. Such surveys rate serious consideration, especially in large urban areas.

Internet Surveys

The primary advantages of Internet-based surveys are their capacity for automated data entry and analysis and, after survey development, the relatively low costs per respondent. Internet surveys are, however, notoriously prone to bias resulting from respondent self-selection. Even if the sample is defined by means other than self-directed responses to a web site, only those with easy access to a computer and on an Internet connection will be included among the respondents. A better use of the Internet than serving as the sole means of survey response is provision of an option for mail or drop-off surveys to be completed online rather than on hard copy that needs to be mailed back. Much of the cost savings possible when using the Internet, however, will not survive this approach.

Telephone Interview Surveys

Telephone surveys overcome some of the problems encountered with mail surveys in that most respondent questions and confusion can be easily resolved. They also typically have a higher response rate than mail surveys. They do, however, incur significant time and staff costs since they are essentially one-on-one surveys. Although up-to-date phone numbers are, like current mailing addresses, difficult to confirm, random digit dialing procedures within selected exchanges can overcome this problem if a geographic sampling frame can be justified. For large sample telephone surveys, a professional commercial or academic survey organization will likely need to be used.

In-Person Interviews

In-person interviews provide perhaps the best quality data as a result of the individual, personalized attention provided to each respondent. Economic considerations associated with the time and resources (e.g., training a sufficient number of interviewers), however, make this option untenable when large sample sizes are needed.

QUANTITATIVE DMS EVALUATION METHODOLOGY

Overview

One of the key benefits of DMSs is their ability to display an almost unlimited number of messages. A particular sign or group of signs has the potential to address an extremely wide range of information desires by motorists. The messages displayed are intended to generate some type of response by motorists approaching and passing the sign(s). It is these changes in behavior that are what must then be quantified through the analysis.

Conceptually, situations where the DMS is used relatively infrequently (i.e., in rural environments primarily for weather-related advisories) require fairly simple and straightforward analyses (although data availability may be a primary limitation). Conversely, urban environments where the DMS may be used almost continuously for incident, roadwork (current and advance notification), special events, weather advisories, and other situations require a more systematic approach to the evaluation process. In high-use locations, a screening process must be employed to identify a finite number of scenarios that can be analyzed with the time and funding resources available. Obviously, the desire is to focus the analyses on those application scenarios that likely yield the most substantial changes in traffic performance.

The methodology for estimating the safety and traffic operational improvements achieved through the installation and operation of DMSs consists of four main steps:

1. Identify and prioritize DMS application scenarios for evaluation.
2. Develop the evaluation plan tailored to DMS applications of interest.
3. Conduct the evaluation.
4. Perform and interpret the evaluation results.

The first two steps ultimately define both the time and costs of the evaluation that will be required (they will also likely dictate how accurately the DMS performance is evaluated). Each of these steps is described in greater detail in the following sections.

Identifying and Prioritizing DMS Application Scenarios for Evaluation

The first step of a DMS analysis is to characterize how the sign or system of signs is used (or, in the case of a planning evaluation, how they are to be used). This characterization includes the following:

- the types of applications for which the signs are used (incidents, roadwork activities, special events, adverse weather/pavement condition warnings, etc.);
- the relative frequency of their use by type of application, time of day, problem location, direction of travel, and impact upon roadway capacity, if applicable; and
- duration of use per usage.

Historical records of device utilization and/or incident logs are the most logical sources of information upon which to base this characterization. Depending on the amount of data available and frequency of use, the characterization process can be based on average conditions or on relative distributions across one or more of the parameters. For instance, Table 3 illustrates a hypothetical characterization of DMS use in a freeway corridor where distributions by time of day, effect on roadway capacity, and durations of use are all estimated. Once DMS usage is characterized in this fashion, the analyst can assess these values to determine which scenarios are expected to result in the most substantial changes in traffic performance, and which are likely to yield only minimal changes in driver behavior and thus whose effects will be more difficult to capture. Those scenarios expected to not contribute significantly to the overall summation of DMS impacts can be eliminated as a means of establishing a manageable evaluation plan. In the example characterization of Table 1, for example, the analyst might decide not to assess the impacts of DMS notifications of shoulder incidents during nighttime because traffic volumes on the facility are known to be fairly low at that time, and so the expected change in driver response would be extremely difficult to capture. Likewise, the decision may also be to not evaluate full roadway closure incidents at nighttime off-peak periods. They occur so infrequently relative to the other possible scenarios that could also be evaluated, and the effort to evaluate them may exceed the anticipated return in evaluation accuracy.

The analyst may also choose to consolidate cells (splitting a percentage in a cell between those on either side) in order to reduce the number of cells for which analysis is required. Thus, a final DMS use characterization table might ultimately look like something similar to Table 4.

DEVELOPING THE EVALUATION PLAN

Once DMS utilization has been characterized and prioritized as discussed above, the next step is to identify and develop the evaluation plan that provides the best estimate of expected driver responses to each of the types of applications that have been identified for the DMS of interest. Driver responses that can be quantified and eventually equated to a dollar figure (a key goal of this project) are limited to either safety improvements (reduction in crashes) or mobility improvements (reductions in delay and stops).

Table 3. Hypothetical Example of Detailed Characterization of DMS Use.

Type of Application	No. per Week	%	Time of Day	%	Effect on Capacity (Lanes Open/Closed)	%	Duration (%)			
							15	30	60	120
Incident Notifications	40	75	AM Peak (6 am–9 am)	30	3/0 (shoulder)	40	20	50	25	5
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	5	15	30	45	10
			Daytime Off Peak (9 am–4 pm)	20	3/0 (shoulder)	40	20	50	25	5
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	5	15	30	45	10
			PM Peak (4 pm–7 pm)	40	3/0 (shoulder)	40	20	50	25	5
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	5	15	30	45	10
			Nighttime Off Peak (7 pm–6 am)	10	3/0 (shoulder)	40	20	50	25	5
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	5	0	30	45	25
Roadwork Notifications	4	3	Daytime Off Peak (9 am–4 pm)	100	2/1	75	0	0	0	100
					1/2	25	0	0	0	100
Etc.			Etc.							

Table 4. Hypothetical Example of Reducing and Consolidating DMS Use.

Type of Application	No. per Week	%	Time of Day	%	Effect on Capacity (Lanes Open/Closed)	%	Duration (%)			
							15	30	60	120
Incident Notifications	60	75	AM Peak (6 am–9 am)	30	3/0 (shoulder)	40	20	50	25	5
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	5	15	30	45	10
			Daytime Off Peak (9 am–4 pm)	20	3/0 (shoulder)	▨	▨	▨	▨	▨
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	▨	▨	▨	▨	▨
			PM Peak (4 pm–7 pm)	40	3/0 (shoulder)	40	45	▨	50	5
					2/1	35	55	▨	40	5
					1/2	20	45	▨	45	10
					0/3 (full closure)	5	30	▨	60	10
			Nighttime Off Peak (7 pm–6 am)	10	3/0 (shoulder)	▨	▨	▨	▨	▨
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	▨	▨	▨	75	25
Roadwork Notifications	4	3	Daytime Off Peak (9 am–4 pm)	100	2/1	75	▨	▨	▨	100
					1/2	25	▨	▨	▨	100
Etc.			Etc.							

Note: Cells shaded will not be assessed in the evaluation.

Improvements in safety via DMS use are believed to be achieved by increasing awareness and preparing motorists for downstream hazards (presence of queues or closed travel lanes, degraded visibility or pavement conditions, etc.) such that motorists are better prepared for the conditions they are about to encounter and are less likely to cause or be involved in a mishap themselves. While operational surrogate measures of safety are sometimes used for evaluation purposes (i.e., measuring differences in speeds approaching the back of a traffic queue), the connection between these measures and true safety improvements is typically not defined at all or is based on very weak correlations.

Improvements in mobility can be achieved either through improved traffic flow through the system (less turbulence) that results in higher capacities, or by effecting a redistribution of traffic through diversion that reduces traffic demands at a bottleneck and thus reduces congestion and delays. The reduction in delay is then converted to an equivalent dollar savings by multiplying a value of time by the delay reduction. Any savings in fuel consumption that occurs due to the traffic redistribution process can also be converted to an equivalent dollar amount as well and added to the delay savings. This reduction in delay is offset somewhat by the longer travel distances that may be required of those choosing to divert. The ability of the analysis to account for travel distance increases depends on the size of the roadway network considered in the evaluation.

Although in theory both types of improvements could be achieved through many of the DMS applications that are possible, it will typically be very difficult to assess safety improvements in high-volume urban corridors that are solely due to the presence of DMSs. This is because the traffic surveillance infrastructure necessary to support DMS operations will also most likely be used to enhance commercial radio reports, Internet websites, reduced incident durations, etc., all of which may also improve safety in the corridor.

At the same time, it may also be difficult to assess any mobility improvements due to DMS use in a rural application, where the signs are installed primarily to provide adverse weather and pavement condition information. In these situations, a lack of feasible alternative routes and even the lack of accurate traffic volume and speed data along the roadway corridor may all conspire to limit consideration of DMS benefits to safety improvements.

Establishing a Safety Improvement Evaluation Plan

The background section included a brief discussion of the process needed to perform a standard before-after crash comparison to assess safety benefits of DMS installations. The roadway length used for evaluation purposes should extend from just upstream of the first DMS sign in the segment that is being evaluated to beyond the expected limits of the DMS's influence in the corridor (dependent upon the entering and exiting travel patterns of the travelers on that roadway segment). On freeway facilities in rural areas where most of the traffic is long-distance travelers, the influence area may be 10 or 20 miles in length. Urban areas, on the other hand, may have potential influence lengths of only a few miles.

As noted, at least 3 years of crash data prior to the implementation of the DMS should be used to establish the "before" crash trends as a way of reducing any regression-to-the-mean effects that may be present. If possible, comparison sections of similar geometric and traffic characteristics, but without the influence of DMS installations, should also be selected to account for any external changes (i.e., increased traffic volumes, highly different weather patterns, etc.) that might also influence crash frequencies and types in the region. If such a comparison segment is not available, then an adjustment for changes in traffic volumes over time along the roadway segment being evaluated must be made. Over a multi-year period of analysis, a roadway or corridor where a DMS system has been deployed may experience growth in traffic volume. In that, some portion of vehicular collisions are directly proportional to traffic volume due to probability of conflicts; increases in traffic volume influencing crashes must be accounted for and appropriate adjustments made to the "after" DMS installation crash experience. This adjustment to after crashes due to traffic growth is made with the following calculation:

$$\text{Reduction \%} = \frac{\text{After Volume (ADT)} - \text{Before Volume (ADT)}}{\text{Before Volume (ADT)}}$$

After DMS installation, crashes are reduced by this calculated traffic growth percentage to allow a "normalized" comparison of effect.

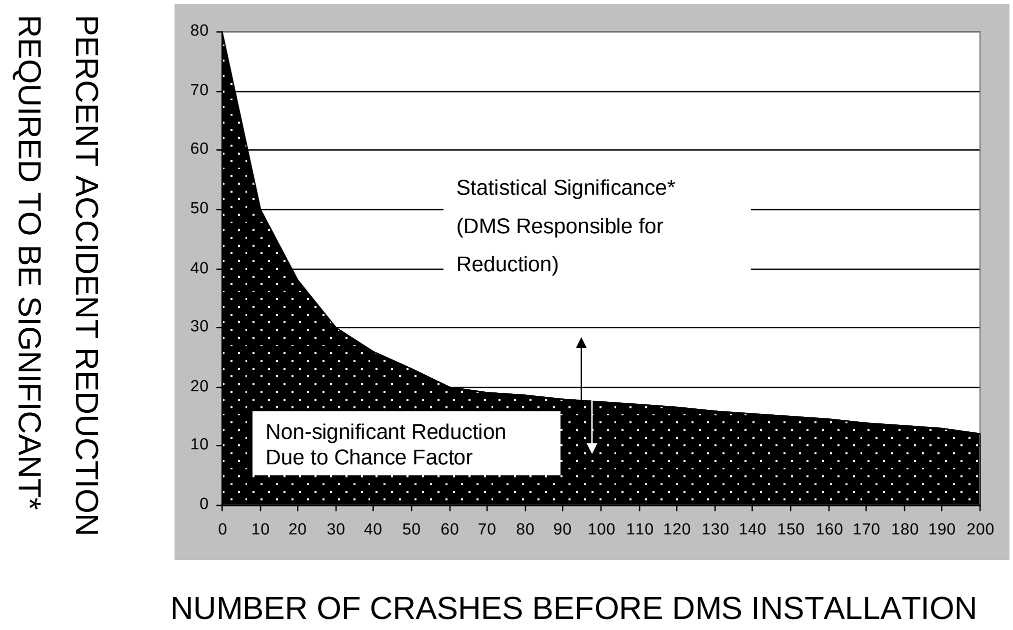
The specific crash types that should be examined and compared at a given location between the before-and-after time periods will depend on the actual DMS application types (and corresponding driver responses anticipated) that were selected for evaluation. In urban areas, for example, safety benefits may be expected through DMS use by warning motorists of downstream congestion caused by earlier incidents (i.e., reductions in secondary crashes) and by encouraging safer driving during adverse weather/pavement conditions. In this case, the analysis should be directed toward assessing both secondary crashes and adverse weather conditions primarily. In rural areas, it may be only the adverse weather events that are of interest to the analysis, if volumes are such that other types of incidents where secondary crashes could occur do not occur with any regularity.

Ideally, the crash analysis should include multiple years of after data since regression-to-the-mean effects may also arise during this time. In reality, the after period may be limited to only 1 year's worth of data, or even less than a full year. If the latter condition occurs, the comparison to the before data should be based on comparable months (i.e., use only part of each year of before data that matches the after period data that are available). A reduction in crashes along a route or corridor where a DMS has been deployed may or may not have been the result of effective DMS performance. The comparison of before DMS installation crashes to after DMS installation crashes must be tested for statistical significance to establish at a given confidence level (95 percent) if the measured reduction occurred by change probability or the result of DMS influence.

Figure 4 illustrates a simple chi-square test for statistical significance of before-after crash reduction under DMS deployment if a comparison section is not used.

If a suitable comparison section has been identified, the calculation of the change in crashes (in total or for each of the subcategories of interest) is computed as a simple cross-product ratio:

$$\% \text{ Change} = \left[\frac{\left(\#\text{ of Before Crashes}_{\text{comparison}}\right)\left(\#\text{ of After Crashes}_{\text{DMS section}}\right)}{\left(\#\text{ of After Crashes}_{\text{comparison}}\right)\left(\#\text{ of Before Crashes}_{\text{DMS section}}\right)} - 1 \right] \text{x } 100\%$$



*At 95% Confidence Level

Figure 4. Chi-Square Example.

The change can be assessed statistically by transforming the ratio into a standard normal statistic:

$$Z = \frac{\ln\left(\frac{(\#\text{ of Before Crashes}_{\text{comparison}})(\#\text{ of After Crashes}_{\text{DMS section}})}{(\#\text{ of After Crashes}_{\text{comparison}})(\#\text{ of Before Crashes}_{\text{DMS section}})}\right)}{\sqrt{\frac{1}{(\#\text{ of Before Crashes}_{\text{comparison}})}+\frac{1}{(\#\text{ of Before Crashes}_{\text{DMS section}})}+\frac{1}{(\#\text{ of After Crashes}_{\text{comparison}})}+\frac{1}{(\#\text{ of After Crashes}_{\text{DMS section}})}}}$$

Regardless of the analysis approach selected, costs must be associated with each individual type of crash that is estimated to have been reduced through the implementation and utilization of the DMS in the corridor. These costs may be referenced from the National Safety Council (NSC) and are given for 2004 as follows:

- fatal (K)—$3,760,000;
- type A—$188,000;
- type B—$48,200; and
- type C—$22,900.

Establishing a Mobility Improvement Evaluation Plan

The effectiveness of DMSs in improving traffic operations would ideally be evaluated on the basis of historical data collected before and after DMS deployment. Unfortunately, the operational measures of effectiveness (MOE) of interest that can be converted into economic value travel time and delay are difficult to measure in the field at the level of accuracy needed for comparison evaluation. Other MOEs such as fuel consumption and environmental MOE (e.g., vehicle emissions) are not measurable directly in the field under any circumstances. The detection systems (e.g., loop detectors, sensors, or video detection) required for the continuous monitoring of these data are commonly installed in connection with the deployment of DMSs and traffic management centers (TMCs). They are either missing or very limited prior to DMS deployment at most locations. Therefore, the "before" data that would be required to establish a baseline, or frame of reference, for DMS evaluations are often not available. The situation is just the opposite for future system installations. In such cases, the "after" data are not available, and therefore, only expected system benefits can be predicted.

Traffic simulation models can play an important role in DMS evaluations. They have been found effective in evaluating advanced traveler information systems (ATIS), advanced traffic management systems (ATMS), and various ITS technologies. They can evaluate the performance of existing DMS systems and predict the expected benefits of future DMS installations.

The primary advantage of using traffic simulation is that the expected operational benefit of a DMS can be estimated for any combination of traffic, roadway conditions, and incident situations that are rarely encountered and therefore very difficult to observe in the field. At locations where the detectors and sensor required to collect system-wide before and after study data for evaluating DMS effectiveness are missing, a properly calibrated traffic simulation model may be the only means of reliably estimating the effect of DMS messages on traffic operations on the entire freeway arterial network. Also, the run time required for simulating multiple scenarios (e.g., combinations of different traffic demands, incident durations, and variations in traffic control strategies) is much shorter than the time required for the field observation of a single event.

The evaluation plan to estimate the mobility benefits of DMS implementation includes the following considerations:

- identifying the appropriate scope of the analysis (network level or freeway level),
- identifying an appropriate analysis tool,
- determining data requirements,
- calibrating the tool to known conditions,
- determining the incremental effect of the DMS upon driver responses,
- calculating changes in operational measures for each DMS application scenario of interest, and
- converting operational improvements into economic value.

Identifying the Appropriate Scope of the Analysis

A DMS intended to reduce congestion on a freeway section by diverting traffic to alternate routes may have a significant effect on traffic conditions on the connected roadways as well. It is particularly true for urban areas with high traffic volume on the arterial network connected to the freeway, but may be less important in suburban or rural areas. Therefore, DMS effectiveness in urban areas should be evaluated on the basis of its impact on the entire affected freeway arterial network. This type of evaluation is referred to as *network-level DMS evaluation.* A simulation network for evaluating the effectiveness of a DMS on a combined freeway arterial system is illustrated in Figure 5.

Simulation network boundaries can be determined based on a detailed knowledge of the arterial network connected to the freeway. All intersections, which may be significantly affected by the increase in traffic demand due to vehicle diversion from the freeway, have to be part of the simulation network. Nearby sources where considerable traffic is generated (e.g., shopping centers) should also be included. In case of existing DMSs, experience gained during previous traffic diversions can be particularly helpful in identifying the boundaries of the network that may be affected. At some locations, there is historical evidence that vehicles diverting from the freeway primarily use the frontage road as an alternate route. In such cases, typically, a reduced size network consisting of the freeway, frontage road, and a few arterials intersecting with the frontage road may be sufficient.

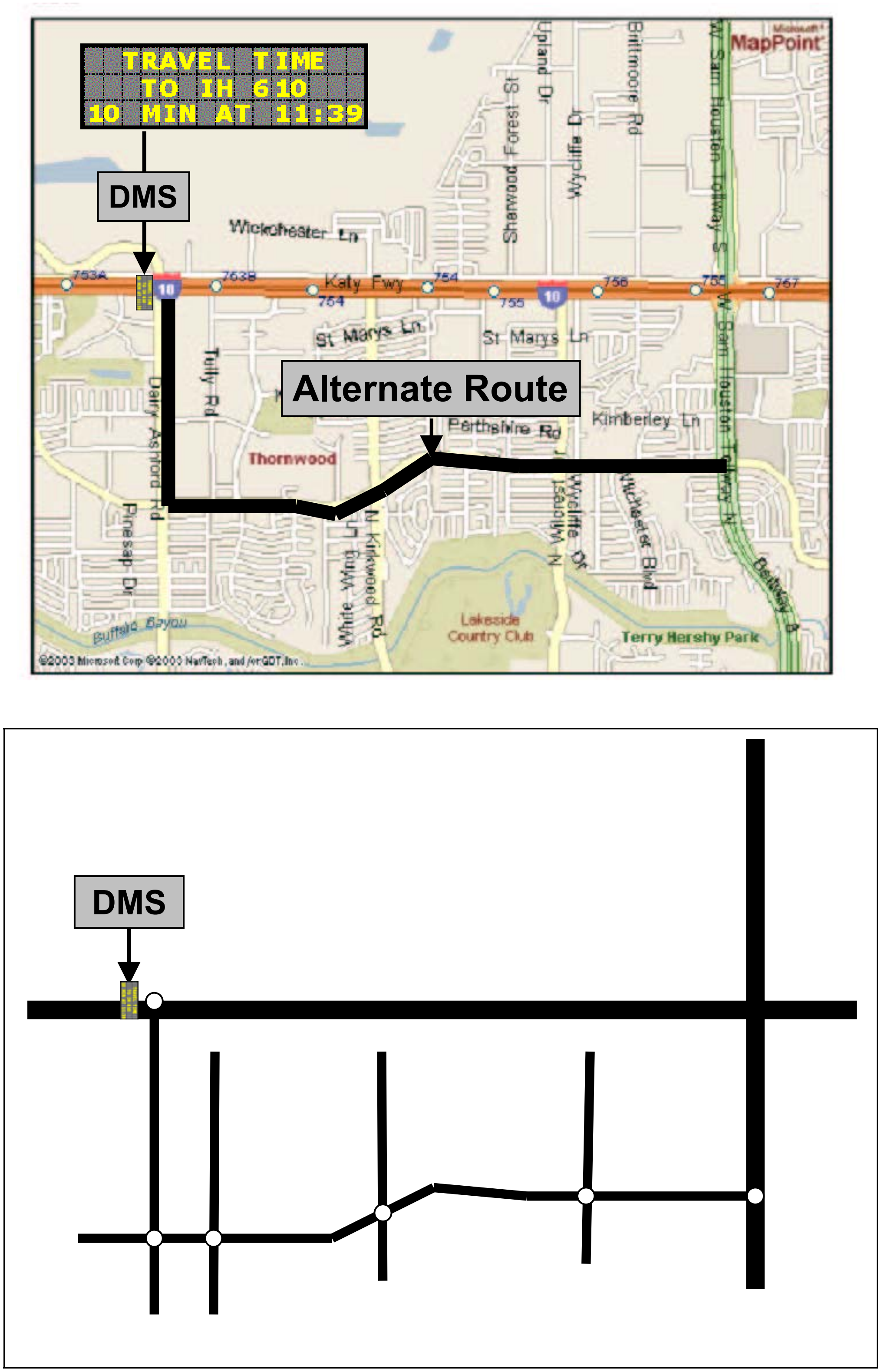


Figure 5. Simulation Network to Evaluate DMS Effectiveness at the Network Level.

In some areas where the freeway is connected to a relatively low-volume and high-capacity roadway network, it is reasonable to assume that the portion of traffic diverting from the congested freeway in response to DMS messages will not exceed the capacity of the alternate route and, therefore, will not cause further congestion and delay. In such cases, it may be sufficient to only consider the changes in freeway traffic in order to evaluate the effectiveness of DMS messages. This type of evaluation is referred to as *freeway-level DMS evaluation*.

Identifying an Appropriate Analysis Tool

The operational and environmental effects of a DMS message that encourages traffic diversion to an alternate route can be modeled using several microscopic traffic simulation models (e.g., CORSIM, VISSIM, INTEGRATION, PARAMICS, and MITSIM). However, evaluation of the effectiveness of a DMS message about future changes in traffic control is a more complex task because these advance information communications are typically disseminated through several other channels in addition to the DMS. The contribution of these different information sources to the entire system benefit is very difficult to estimate. Dynamic route-choice algorithms mimic the entire traveler information system effect, not just the incremental effects of the DMS (the extent to which the algorithms themselves even represent the combined effect of traveler information on driver behavior is a subject of debate at this time). Therefore, factors other than the representation of dynamic route-choice behavior should be used to determine which tool is selected for use. Once the tool is selected, the analyst will need to be able to explicitly alter traffic volume inputs to represent the estimated effect of the DMS on route-choice behavior. This alteration of demand is corridor or region specific and computed based on stated preference surveys of motorists using that corridor (this process is described in greater detail below).

Determining Data Requirements

One of the disadvantages of performing an evaluation using microscopic simulation tools is the large amounts of data needed. For example, the following data are required for setting up a simulation model for evaluating DMS effectiveness:

- Geometric data—Number of lanes, lane widths, location of lane additions/drops, grade levels, and entry and exit ramp locations need to be specified for the entire network of interest.

- Speed data—Speed limits and/or free-flow speeds for roadway sections are needed.
- Volume data—Traffic volume data are needed at each point where vehicles can enter the network.
- Incident data—The time of onset, duration, location and affected roadway length, and number of lanes closed are needed. These data come from the DMS application scenarios to be evaluated as defined previously.
- Traffic control—For network-level evaluations, stop or yield signs, signalized intersection phases, timing plans, detector locations, and lane configurations are needed.

Calibrating the Tool to Known Conditions

Calibration of the analysis tool to known conditions is a critical, but often overlooked, step in the use of traffic operations analysis tools. If the DMSs are already installed along the travel corridor, calibrating to conditions to all or at least some of the DMS application scenarios of evaluation interest is the preferred approach. Then, when the incremental changes in route choices due to DMS information are estimated via survey techniques described below, input traffic volumes can be adjusted accordingly to estimate the expected traffic conditions that would have resulted if the DMS had not been present.

The model output used in the calibration process depends on observation data availability. The two outputs that are most likely to have field data counterparts are link flows and average speeds. If travel times were recorded (or estimated from speed data), they can also be compared to simulated travel times. Observations on queue sizes are also useful for model calibration. Most calibration parameters that may be adjusted in the models are related to either vehicle or driver characteristics. Typical driver behavioral parameters such as gap acceptance, car-following sensitivity, and minimum headway may be adjusted to meet existing link capacities. Another important parameter is the maximum (emergency and non-emergency) deceleration that may be specified for different vehicle types. Since minimum headway is a function of maximum deceleration, altering these rates gives the modeler some control over the density of the system. Other parameters related to lane-changing maneuvers are also important to calibrate the model, particularly when the network includes lane closures, exit and entry ramps, or weaving sections.

Proper selection of the type of probability distribution (e.g., uniform, normal, or Erlang) for generating vehicles at entry points may also be important.

In summary, the data desired for the calibration of the simulation model are the following:

- Volume data—traffic counts measured in selected points of the network;
- Speed data—average speeds in selected points of the network;
- Travel times—travel times measured on freeway and alternate routes;
- Queuing—time when queues began forming, and time when traffic returned to normal condition; and
- Queue size—length of maximum queue.

Determining Incremental Effect of DMSs on Driver Responses

A specific type of survey has been increasingly used in recent years to predict and model driver behavior in relation to transportation facility improvements such as DMSs. Based largely in economic theory and marketing applications, a family of survey techniques, known as "stated preference," has been developed wherein respondents are asked to choose between various options. These surveys offer a means for evaluating existing and planned DMS-equipped facilities in terms of the impact of specific DMS characteristics on the choices drivers make when confronted with a given DMS message at a particular location. The primary decision of interest here is the binary choice a driver makes to divert or not divert from his or her normal route. The same approach can be used to estimate significant changes in speed selection or other driving actions that depart from the norm. Stated preference surveys ask respondents how they would behave in specific, well-defined hypothetical situations. Stated preference surveys can be especially important for estimating the incremental effects of DMSs on driver responses particularly when no (or limited) operational data relevant to diversion are available.

The results of stated preference surveys can be used directly to estimate the impacts of a DMS improvement, or in their more sophisticated application, as proposed here, surveys can be developed that can be used in conjunction with other data to support quantitative simulation models. The goal here is to provide valid and reliable estimates of the percentage of diverting traffic under multiple scenarios.

Researchers note that a criticism of stated preference data is that drivers may react differently to what are essentially hypothetical experiments conducted by means of surveys than they would when facing the same alternatives on a real DMS-equipped facility. One means for identifying biases in stated preference responses is to design the survey so that at least some of the measured preferences can be validated against observed responses. Evaluations of yet to be implemented DMS systems negate this option and, even in evaluations of existing facilities, this option may not be available. The essential steps in developing and conducting a stated preference survey are the same as those for any other type of survey:

1. Determine and implement a sampling method that results in survey respondents who are representative of the appropriate user population. In this case, primary, but not exclusive, interest is likely to be in regular commuters along the DMS-equipped corridor. Other populations, however, may also be important, including local residents who drive on the subject corridor regularly but for non-commuting trips and, particularly on corridors that carry a high proportion of through traffic, non-residents that are unfamiliar with alternate routes or the local area.

2. Determine the type of survey instrument to use. Because of the increased complexity of stated preference surveys compared to other survey types, mail surveys or in-person computer-assisted techniques offer the best options. The latter may be prohibitively expensive for large sample survey efforts.

3. Design the survey instrument. In most cases, stated preference surveys will require development of multiple versions of the survey instrument. This is necessary both to accommodate a sufficient number of hypothetical scenarios to account for the potentially large number of independent variables of interest without overburdening respondents with extremely long and time-consuming surveys and to provide the opportunity to segment the respondents in groups that may require different hypothetical scenarios (e.g., it may be inappropriate to use the same DMS scenarios for both regular rush-hour commuters and attendees at special events for which DMS-displayed communications are provided).

Assuming an appropriate sampling method is followed, design of the stated preference surveys, or more accurately design of the hypothetical choice items of a broader survey that includes stated preference questions, is the most critical and most difficult phase of the whole stated preference survey process. It requires detailed knowledge of the specific road segment(s) or corridor of interest and specific knowledge of the characteristics of the existing or planned DMS configurations, message content, and, in the case of existing DMSs, knowledge of the history of use of specific DMS messages—including the frequency and timing of specific messages displayed on the DMS being evaluated.

Scenarios need to be developed that present a verbal picture of the roadway, DMS, and environmental conditions under which diversion information is sought. The verbal scenarios can be enhanced and made significantly easier to comprehend by inclusion of photographs or realistic graphic representations of the specific DMS (or DMS message) and drivers' "through the windshield" views of a scenario's conditions.

Figure 6 provides a generalized example of the type of hypothetical choice items for which scenarios will need to be developed and the type of choices respondents will be asked to make. Each of the five underlined items in Figure 6 (time of day, number of vehicle occupants, current location relative to incident, roadway condition, and current relative traffic condition) represent variables (for this example) that may influence the respondent's response choice. Changing any or all of these variables provides potential additional scenarios to be tested. A critically important exercise in the design of the survey instrument is determining the most important scenarios to include. This will require that tradeoffs be made to balance the constraints imposed by survey length and number of survey versions required with the need to identify and maximize the number of operationally important scenarios for which diversion estimates are desired. When one considers the very large number of possible independent variables, every level of which adds potential scenarios to be tested, it quickly becomes evident that it is not practical to include all plausible scenarios. Among the candidate variables for inclusion in hypothetical choice scenario development are:

Each of the following items asks you to choose among several possible options.

Please indicate by placing an X in the appropriate box, the one option you would choose based on your current knowledge about driving on I-XX if you were faced with the specific conditions described and pictured below:

ITEM 1

It's 7:15 am, and you are on your drive to work.

You are driving alone northbound in the center freeway lane of Interstate XX.

You are four exits south of 5th Street where you usually leave the freeway.

The road is dry, and traffic appears to be about the same as usual.

On I-XX just prior to 9th Street, you see the following sign:

I-XX NORTH AT
7th STREET
MAJOR ACCIDENT

What would you do?

Place an X in the one box below that best indicates what you would do:

- ☐ Maintain my lane position and continue on I-XX to my usual exit at 5th Street.
- ☐ Move to the right lane and continue on I-XX to my usual exit.
- ☐ Exit the freeway at 9th Street exit.
- ☐ Exit the freeway at 8th Street exit.

Figure 6. Sample Scenario and Hypothetical Choice Item.

- a “null” condition, i.e., no DMS messages;
- various incident types: accidents, lane closures, etc.;
- planned incidents/events;
- time of day, i.e., peak, non-peak;
- weather;
- visible congestion; and
- presence of radio traffic reports or other communication modalities in addition to DMSs.

4. Implement the survey and analyze results. The primary output of the hypothetical choice stated preference surveys can be distilled down to the total number or proportion of drivers expected to exhibit a specific behavior, i.e., divert at specific locations under each of the scenarios examined. With the requisite planning in the sampling and survey design phases, this output, which will subsequently be used as input data for the simulation models, can be segmented by pertinent characteristics of drivers’ trips (e.g., peak travel commute verses off-peak), characteristics of the drivers and their vehicle (e.g., driver age, frequency of respondents’ trips, vehicle type, etc.), and prior experience with DMSs and drivers’ perceptions of DMS accuracy, credibility, and reliability.

Once the percentage of diverting traffic is determined, the diversion process itself can be modeled by either static or dynamic vehicle routing. Static routing assumes that the percentage of vehicles diverting in response to a DMS message is constant over time. In case of dynamic vehicle routing, the percentage of vehicles may change over time in response to downstream traffic conditions on the freeway and the alternate route.

Traffic diversion determined from field observations or surveys is typically represented by a single number, a percentage of freeway traffic, which is considered constant for the entire time period when a warning message is displayed by a DMS. In such cases, whether the assumption of constant diversion is right or wrong, traffic diversion can only be simulated by diverting the same percentage of traffic regardless of downstream traffic conditions. Although it is unrealistic, this approach may produce reasonable estimates for some MOEs (e.g., overall throughput and average delay) in certain cases. If the simulation is used for the evaluation of an existing system, it is also an option to consider the percentage diversion as model parameter and fine tune it during model calibration. However, in the case of new DMS installations, the expected percentage of diverting traffic can only be determined from surveys or field observations conducted at other DMS-equipped locations with similar traffic and roadway conditions.

Traffic diversion using static vehicle routing can be simulated using a number of microscopic traffic models, including CORSIM and VISSIM. As mentioned earlier, the degree of traffic diversion is not only a function of the warning message. It also depends on the actual traffic conditions on the freeway and the alternate route; the vehicle composition (i.e., truck percentage); driver composition (i.e., percentage of commuting and local traffic); and a number of other factors observed by the motorists as they approach the diversion point. Therefore, the percentage of diverting traffic is constantly changing over time, which can only be modeled by dynamic vehicle routing. In dynamic vehicle routing, the simulation model continuously updates the percentage of diverting vehicles by applying certain diversion logic specified by a set *if* (conditions) *then* (consequence) type rules, or a route choice model. For example, a simple logic for rule-based diversion can be formulated in the following manner:

if ($v_1<v$ & DMS msg = ‘ ’) then (expected diversion = 2%)
if ($v_2<v<v_1$ & DMS msg = ‘ ’) then (expected diversion = 3%)
if ($v_3<v<v_2$ & DMS msg = ‘ ’) then (expected diversion = 6%)
if ($v_1<v$ & DMS msg = ‘Right lane closed’) then (expected diversion = 5%)
if ($v_2<v<v_1$ & DMS msg = ‘Right lane closed’) then (expected diversion = 8%)
if ($v_3<v<v_2$ & DMS msg = ‘Right lane closed’) then (expected diversion = 14%)

where v is average vehicle speed observed on the freeway downstream of the diversion point, and v_1 , v_2 , and v_3 are speed thresholds. Several other variables such as average speed on the diversion routes or queue length on the freeway or the exit ramp may also be included as *conditions* in the rules. These rules would be generated from the results of the driver surveys that provided an indication of the sensitivities of diversion behavior in response to both DMS information and roadway conditions.

The Vehicle Actuated Programming (VAP) module of VISSIM and the Run Time Extension (RTE) module of the latest version of CORSIM make it possible to model vehicle diversions using the rule-based logic described above. In addition, a newly released simulation model, DYNASMART-P, that was specifically developed for dynamic traffic assignment and routing should also be considered. It may be particularly useful for evaluating DMS effectiveness on relatively large freeway arterial networks.

Using either the static or dynamic approach to diversion modeling, the MOEs (e.g., travel time, delay, stops, queue length, fuel consumption, and emissions) required for evaluating the effectiveness of a DMS can be calculated for a range of traffic demands and incidents of different types and durations.

Converting Operational Improvements into Economic Value

Once all of the analyses are completed, a series of incremental changes in delay or travel time, fuel consumption, and possibly vehicle stops estimated to be the result of DMS implementation on a roadway segment will exist for each of the DMS application scenarios initially selected for analysis. These incremental changes are then multiplied by the frequency with which they occur in the corridor over the evaluation period of interest. If the intent is to establish a benefit-cost ratio for the DMS installation, then the analysis period would extend over the service life of the DMS equipment. If the intent is to compute the estimated benefits only, then the time period of most interest to the use (i.e., per month, per year, etc.) can be selected.

Once the total amount of vehicle delay reductions, fuel consumption reduction, and/or vehicle stop reductions due to the DMS installation have been summed over the analysis period of interest, each is multiplied by an appropriate economic value and summed to determine the total economic benefit of the sign(s). Although there are some variations in the value of traveler time assumed in analyses, past FHWA publications suggest values of \$10 to \$13 per vehicle-hour for automobiles and \$17 to \$24 per vehicle-hour for trucks (in 1996 dollars). Current fuel prices can be used to estimate fuel consumption benefits, and the same FHWA publications can be accessed to estimate the reduced vehicle operating costs (VOCs) achieved through fewer stops and idling time in queue.

CHAPTER 5: CASE STUDY VALIDATION

SITE SELECTION

The preliminary guideline methodology for DMS performance evaluation discussed in Chapter 4 was presented to the research advisory panel for review. The panel approved these preliminary guidelines to be validated through application in an urban and rural corridor with DMS installations. Houston was selected as the urban case study with Amarillo as the rural case study. I-45 North of Houston exhibits several DMS sites, which have been implemented in that corridor over the past 10 years. In the fall of 2002, TxDOT made operational several DMS installations along the approaches to the I-40 and I-27/US 87 interchange in Amarillo.

DATA PROCUREMENT

The TxDOT districts associated with these case study sites were canvassed for available assessment data. In Amarillo, volume data (2004) were obtained for the I-40 DMS corridor route from the permanent Automatic Traffic Record (ATR) and count stations, and converted from average annual daily traffic (AADT) to design hourly volumes (DHV). This allowed estimates of entry and exit volumes to be used in operational modeling. Data were also obtained relative to the type and frequency of all DMS messages displayed during the period 2003-2005 in the I-40 corridor. Fatal crash data for the Amarillo DMS corridor were obtained from the National Reporting System (NRS) for a comparative 2 year period before and after implementation. Figure 7 gives the geographical and roadway locations for DMS installations in Amarillo.

In Houston, volume data (2004) were obtained for main lanes and all access connections on I-45 North from downtown to the Hardy Tollway Northbound. For the same time period over the indicated freeway section, incident data (excluding construction activities) were obtained for which DMS messages were displayed. Detailed cross-section and longitudinal alignment geometry for I-45 North was also obtained. Figure 8 depicts the I-45 North corridor in plan with DMS locations shown.

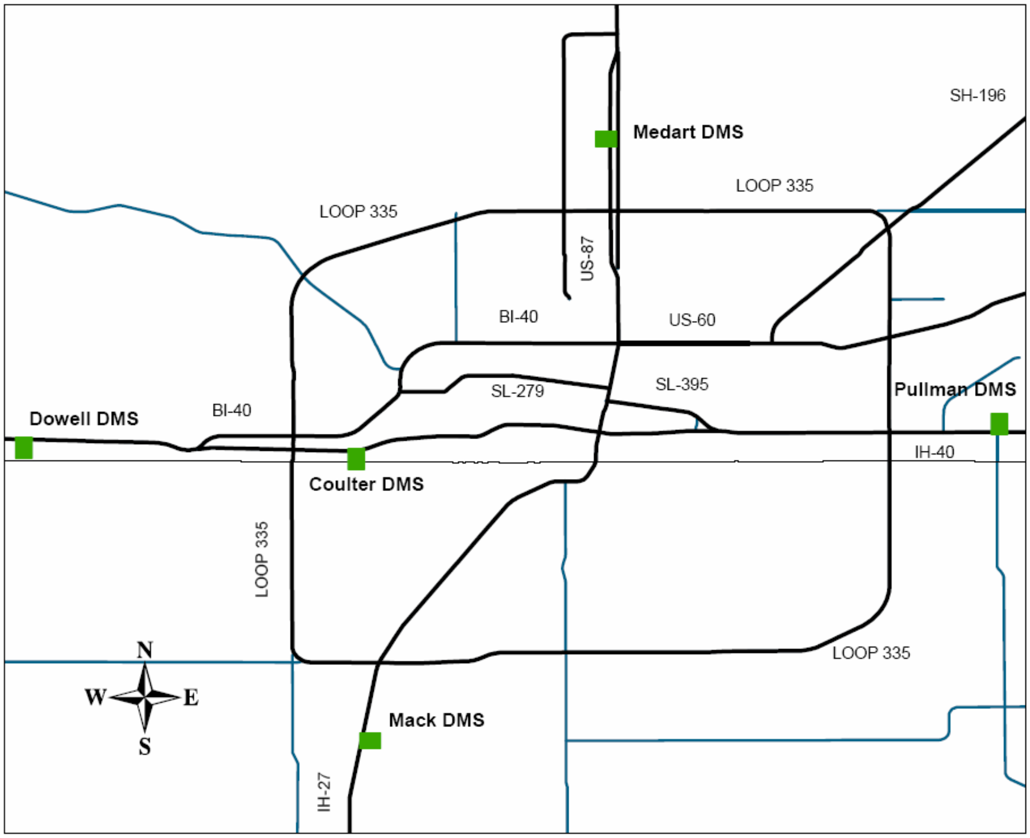


Figure 7. Geographical/Roadway Locations of Amarillo Corridor DMSs.

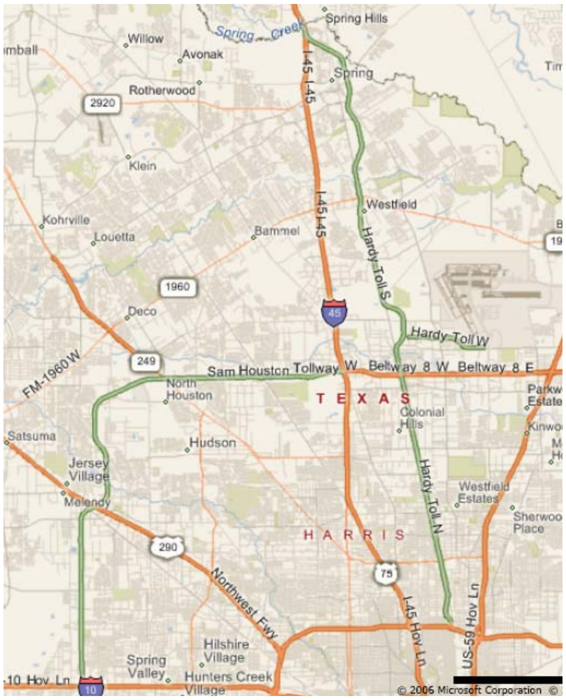


Figure 8. DMS Locations on I-45 North in Houston.

The remainder of this chapter discusses the application of the preliminary guideline methodology for evaluating DMS performance in both the Amarillo and Houston case studies.

AMARILLO CASE STUDY

The Amarillo District of TxDOT, with the support of the Traffic Management Section of the Traffic Operation Division, has deployed DMS technology along the major east-west (I-40) and north-south (I-27/US 87) routes through the Texas Panhandle. This "Phase 1" deployment, which began in 2001, included five DMS sites strategically located along these routes. The objective of the placement and operation of this equipment is to allow effective and timely monitoring and confirmation of traffic and environmental conditions, such as to inform motorists on these routes about safe and efficient travel. All the information retrieved in real time from the field is sent to a TMC that serves as the mainframe of the system. The TMC disseminates all necessary information that is received from its sensors and transmits the information to motorists by the DMS.

MOEs to evaluate the success of DMS equipment deployment and operation in Amarillo focus on mobility (delay) and safety (crashes). A demonstrated reduction in either or both measures from historical data prior to DMS implementation over a sufficient time period after implementation is deemed a quantitative benefit. The primary and most important quantifiable benefit to rural motorists would be to create a safer driving environment for various conditions (which would manifest through a reduction of crashes).

Non-quantifiable (qualitative) benefits associated with efficiency and reliability of the DMS deployment may be assessed from both TxDOT and the users' (travelers') perspectives. Utilization and maintenance will be established from interviews with TxDOT personnel responsible for traffic operations and safety within the designated corridor. Motorist surveys will be conducted to assess public opinion regarding critical safety issues and responsive advisory information to be addressed with DMS technology.

Sign Usage

Table 5 illustrates a total number (292) of message displays utilized in motorist communication on the five Amarillo DMS installations over an approximate 2-year period of operation (January 1, 2003, to March 17, 2005).

Table 5. Amarillo DMS Usage.

Message Type	Display Frequency (N)	Min. Display Time (Hours)	Max. Display Time (Hours)	Mean Display Time (Hours)	Standard Deviation Display Time (Hours)
Accident Ahead	13	2.41	187	48	56
Construction Ahead	86	0.002	2774	81	309
Weather Advisory	22	0.1	223.67	52	71
Public Service	143	0.01	1199	51	149
Sign Testing	40	0.24	48	18	17
Amber Alert	5	7.89	168	67	69
Total for all five DMS locations over an approximate 2-year time period (1/1/03 to 3/17/05)					

Statistics shown in Table 5 for each message display category are minimum, maximum, mean (average), and standard deviation of display time given in hours.

Safety Evaluation

The primary and most important quantifiable benefit to rural motorists would be to create a safer driving environment for various conditions, which would manifest through a reduction in crashes. The reduction would be established through a statistical comparison of the total number and/or type and/or severity of crashes in a rural corridor before implementation and after implementation of DMS technology. Ideally, a minimum period of time for statistical analysis would be 3 or more years for increased confidence that the observed and measured crash reduction was affected by its deployment and operation. Both "t" and chi-square paired statistical comparisons between the numbers of reported crashes before and after ITS deployment should be made at 95 percent confidence levels.

Appropriate frequency adjustments were calculated for changes in traffic volumes. Other identifiable differences in roadway, traffic, and environment were examined for biasing influence on statistical results.

Roadway, traffic, and crash record information for the I-40 and I-27/US 87 corridor were obtained from the TxDOT Roadway Inventory (RI1) file and the Department of Public Safety (DPS) crash record file for the “before” ITS implementation period of 1998-2000. The following points from these data are highlighted as follows:

- The subject ITS corridor, encompassed by the I-40 and I-27/US 87 routes in the Amarillo District, consist of more than 260 miles of controlled access roadway with more than 3.5 million daily vehicle miles of travel (DVMT).
- The subject corridor has experienced more than 600 crashes per year with an average of six crashes per year being fatal in the time period 1998-2000.
- More than 60 percent of these crashes occurred during daylight conditions and more than 95 percent on straight, level roadway alignment.
- Approximately 20 percent of these crashes were weather related while approximately 10 percent occurred while the subject roadways were under construction.

ITS deployment was in progress from 2001 to 2002 in the subject corridor, and as a result, this time period was not considered in the safety evaluation. Crash data for a comparable after deployment time period (2003-2005) were anticipated to be available and accessible through the newly developed TxDOT/DPS CRIS. However, problems and delays in CRIS activation have prevented gaining access to any crash data after 2001. Fatal crash data are available from the national Fatality Analysis Reporting System (FARS) for the Amarillo ITS corridor for a 2-year period before and after implementation. There were 21 fatal crashes prior to DMS deployment along the corridor routes compared to 16 fatal crashes after DMS deployment in the Amarillo District along corridor routes.

Adjusting for an increase in volume of approximately 9 percent over a 4-year analysis period yields an expected number of post-implementation fatal crashes in the subject corridor of 23 in the 2-year after period. This represents a decrease in fatal crashes along exposed routes in the Amarillo DMS corridor of seven, or an approximate 30 percent decrease. Using the NSC comprehensive societal cost (2004) for a fatal traffic crash of $3,610,000 multiplied by the 2-year (2003-2004) decrease of seven fatal traffic crashes in post-implementation expected crashes along primary routes in the Amarillo ITS corridor yields total accrued safety benefits of approximately $25.27 million dollars.

Motorist Opinion Survey

A motorist opinion survey concerning DMS operations in Amarillo was conducted at a farm and ranch show in December 2003 and at a car show March 6-7, 2004. An example of this survey instrument is shown in Appendix A. A summary of these results is as follows:

- More than 80 percent of the motorist opinion survey respondents were daily/weekly drivers in corridor routes, while slightly less that 20 percent drove the subject routes monthly or less.
- Of the 164 motorist opinion respondents, all were drivers of small vehicles except for 2 percent who were long-haul 18-wheeler drivers.
- Almost all (95 percent) of the after-implementation survey respondents had seen electronic message signs used for roadway information display.
- Motorist opinion survey respondents indicated that “construction/maintenance” was the most frequent information displayed on electronic message signs (40 percent) followed by “weather-related advisory activities” (20 percent). Both “accident and/or road hazard warnings” and “road closure and/or detours” were displayed equally less frequently (14 percent).
- In contrast to what is usually displayed on electronic message signs, the motorist opinion respondents indicated that “weather-related advisory activities” was the most important information to be displayed on electronic message signs (30 percent), followed closely by both “construction/maintenance” (23 percent) and “accident and/or road hazard warnings” (25 percent). “Road closure and/or detour” was indicated as least important (15 percent).

- More than 85 percent of the motorist opinion survey respondents indicated that they do read the information posted on the electronic roadway signs “always or most of the time.”
- Slightly less that half (45 percent) of the motorist opinion respondents indicated that they have tuned their radios to a posted frequency to get roadway information. Of that 45 percent, almost 90 percent indicated that the information was helpful.
- Approximately one-third (35 percent) of the motorist opinion survey respondents had ever used cell phones to obtain roadway information.
- More than 90 percent of the motorist opinion survey respondents agreed that the information posted on electronic roadway message signs was accurate.
- More than 80 percent of the motorist opinion survey respondents either “agree or “strongly agree” that:
    - The overall implementation has been positive.
    - The messages have personally helped them while traveling.
    - Roadways are safer as a result of the signs.
    - They would like to see more electronic roadway signs in the future.
- The gender of the motorist opinion survey respondents was approximately equal, with 55 percent being male respondents and 45 percent being female respondents.
- The most common age group of the respondents was “26-65 years” (70 percent), followed by “16-25 years” (20 percent). There were a small number of respondents in the age group “over 65 years” (10 percent).
- The highest education level obtained by the survey respondents was “college or associates degree” (40 percent), followed closely by “high school diploma” (35 percent). There were an even smaller percentage of respondents with “less than high school” education (15 percent). The least common education level obtained was “graduate degree” (8 percent).

Mobility Assessment

The effectiveness of rural corridors utilizing DMSs for improving traffic operations and safety would ideally be evaluated on the basis of historical data collected before and after DMS deployment. Although safety data are typically available from accident reports, MOEs such as travel time, delay, queue, length, fuel consumption, and environment effects (i.e., vehicle emissions) are often not available. The detection systems (i.e., loop detectors, sensors, or video detection) required for the continuous monitoring of these data are commonly installed in connection with the deployment of DMSs and TMCs. They are either missing or very limited prior to DMS deployment at most locations; therefore, the “before” data that would be required to establish a baseline, or frame of reference, for DMS evaluations are often not available. The situation is just the opposite for future system installations; in such cases, the “after” data are not available and only the expected system benefits can be predicted.

The actual driver responses to displayed DMS real-time information may be measured quantitatively to assess mobility. DMS performance as a result of timely and appropriate driver responses may improve mobility on a roadway or corridor by reducing delay as measured by:

- shorter queues,
- less average delay per vehicle,
- shorter travel times for a given trip length, and
- reduced total vehicle delay.

Effective DMS performance will influence or generate motorist diversion from an impacted roadway, thus reducing vehicle demands for available capacity and distributing traffic on alternate routes. Mobility benefits of effective DMS performance may also be quantitatively established through higher measured travel speeds and increased facility throughput of bottlenecks to improve LOS. Efficient DMS communication can improve overall traffic flow and maintain beneficial V/C ratios. Time of incident-related capacity restrictions can also be minimized.

Developing “matched” pre- and post-DMS installation data for mobility benefit analyses is much more difficult. From a mobility assessment standpoint, it would be desirable to quantify volumes, speed, delay, queue lengths, and diversion along a potential roadway under consideration for DMS implementation. However, most rural districts do not have the resources (detection equipment) in place to collect these data in either a before or after implementation condition. Some anecdotal information may be available or possible to produce from known incidents, but unless recognized and accounted for early in the planning for a rural DMS system corridor, the capacity to collect the necessary data to establish mobility benefits does not exist.

Other difficulties are manifested in measuring true mobility benefit indicators that can be fiscally accounted for. For example, queue lengths can be correlated with vehicle delay and valued, but unless all traffic volume is measured in and out of a given incident queue over time, a complete assessment cannot be made. In an analysis of input-output volumes along a facility with DMS communication, it is difficult to establish the differences in approach volumes, which are the result of DMS influence as opposed to other factors that cannot be accounted for (i.e., lower traffic due to public radio advisories).

As a result of these difficulties, roadway/traffic simulation models seem to offer a viable means to isolate DMS mobility benefits while maintaining control of other influencing variables. In fact, a properly calibrated traffic simulation model may be the only means of reliably estimating the effect of DMS messages on traffic operations on the entire freeway arterial network. The run time required for simulating multiple scenarios (i.e., combinations of different traffic demands, incident durations, and variations in traffic control strategies) is much shorter than the time required for the field observation of a single event. Simulation analysis does require some detail of a prior knowledge, or reliable estimates, of motorist response to DMS communication.

Simulation models currently are lacking in terms of adequately capturing the dynamic diversion decision-making processes that occur in a transportation network. As a result of these deficiencies, the percentage of motorist diversion or expected speed reduction response must be explicitly accounted for by the analyst during the simulation process in order to achieve reasonable calculations of effects.

Output from before-after comparative mobility benefit analyses includes totals for reduction in:

- delay and travel time with associated costs,
- queue length and queue volume, and
- fuel consumption/air emissions with associated costs.

While delay, travel time, and queue length measurements are difficult under the best conditions, it is indicated that with proper diversion estimates and calibration these parameters may be obtained through simulation.

Incident Diversion Survey

A critical input for the simulation-based mobility assessment of DMS-displayed messages within the Amarillo rural corridor is the percentage of traffic diversion in response to the displayed advisory messages. This diversion percentage may be determined from field observations, estimated from motorist surveys, or predicted from an empirical route choice model. To facilitate the mobility assessment, a survey was conducted on motorists traveling the two primary routes (I-27 and I-40) within the Amarillo corridor.

TTI research teams surveyed motorists on I-27 and I-40 in Amarillo, Texas, over the 3-day period of January 11-13, 2005. The survey schedule was designed to maximize exposure to motorists and truck drivers who usually travel on the roadway of interest (I-27 or I-40). Two-person teams administered surveys from 8 am-12 pm and again from 1 pm-5 pm. One team surveyed the DPS office located on Canyon Drive (off I-27) over the 3-day period, while the other team surveyed at different travel plazas including Loves Travel Stop (Exit 74A) and Flying J's Travel Plaza (Exit 74), both located off I-40.

Surveyors approached potential respondents and asked their willingness to participate in a brief survey, and if the person agreed, a screening question was asked to determine how often the person traveled on the roadway of interest. Surveyors verbally asked questions and recorded responses on the survey form. Of a total of 627 surveys, 509 (81 percent) indicated traveling on the roadway of interest more than two times per year and were included in the survey sample. Additionally, the survey instrument contained questions related to roadway travel, DMSs, and demographics. Respondents were also shown a card with hypothetical DMS messages and given a series of responses regarding what they would do if they encountered such a sign while driving on the roadway. Participants with odd-numbered surveys were shown messages related to road construction, while even-numbered survey respondents were shown messages related to an accident.

The survey sample included a total of 509 respondents who indicated that they traveled on I-27 or I-40 more than two times per year. Analyses were conducted on all respondents, as can be seen in Table 6, and on three groups who were defined by how often they traveled the roadway and the type of vehicle they drove. Among respondents most indicated that they were frequent users of the roadway; a total of 426 respondents (83.7 percent) claimed they travel on the interstate at least once a week (21.4 percent) or daily (62.3 percent). Over three-fourths of all respondents (78.4 percent) said that they usually drive a car, pickup truck, or a sports utility vehicle (SUV) while traveling on the roadway. Almost one-fifth of the respondents (19.4 percent) indicated that they usually drive tractor-trailers or other large commercial trucks while traveling on the roadway. The predominant reasons cited for using the roadway were to travel to/from work/school (46.2 percent), local trips (shopping, medical, etc.) (36.3 percent), and as part of their job (28.1 percent). Among the respondents that use the road as part of their job, most said that they were driving through the area (74.8 percent) and/or making local deliveries (39.2 percent). The majority of all respondents were from local (Potter and Randall) counties (72.7 percent), out of state (11.6 percent), and other surrounding Texas Panhandle counties (8.8 percent).

The first group is defined as "regular road users," which includes respondents who indicated that they traveled on the roadway of interest daily or at least once a week (n=426). Most regular road users drove personal cars, pickups, or sports utility vehicles (82.6 percent) and tractor trailers or other large commercial trucks (15 percent) on the roadway of interest. More than one-half of the regular road users were traveling to/from work/school (53.8 percent), making local trips (37.6 percent), or driving as part of their job (22.3 percent). Among regular road users traveling as part of their job, most were simply driving through the area (65.3 percent) and making deliveries in the local area (45.3 percent). Most regular road users were from local area counties (81.7 percent) and other surrounding counties in the Texas Panhandle (8.0 percent).

The second group referred to as "all tractor-trailers" is defined as those who indicated driving a tractor trailer or other large commercial truck while traveling on the roadway (n=99). More than one-half the tractor-trailer drivers (64.7 percent) used the roadway of interest daily or at least once a month and, thus, were also part of the group classified as frequent road users. As

Table 6. Characteristics of Road User Groups.

	All Respondents		Regular Road Users		All Tractor Trailers		"Through" Tractor Trailers	
Characteristic	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Frequency of travel								
Daily	317	62.3	317	74.4	28	28.3	15	20.3
At least once a week	109	21.4	109	25.6	36	36.4	29	39.2
About once a month	50	9.8	0	0.0	20	20.2	15	20.3
Less than once a month	33	6.5	0	0.0	15	15.1	15	20.2
Total	**509**	**100.0**	**426**	**100.0**	**99**	**100.0**	**74**	**100.0**
Type of vehicle*								
Car/pickup/SUV	399	78.4	352	82.6	2	2.0	1	1.4
Small service or delivery truck	12	2.4	11	2.6	0	0.0	0	0.0
Tractor-trailer or other large commercial truck	99	19.4	64	15.0	99	100.0	74	100.0
Other	2	0.4	2	0.5	0	0.0	0	0.0
Total	**512**	**100.6**	**429**	**100.7**	**101**	**102.0**	**75**	**101.4**
Trip purpose*								
To and from work or school	235	46.2	229	53.8	4	4.0	1	1.4
Other local trips	185	36.3	160	37.6	2	2.0	1	1.4
On road as part of job	143	28.1	95	22.3	97	98.0	73	98.6
Total	**563**	**110.6**	**484**	**113.7**	**103**	**104.0**	**75**	**101.4**
If on road as part of job*…								
Making deliveries or similar	56	39.2	43	45.3	39	40.2	16	21.9
Driving through area	107	74.8	62	65.3	74	76.3	74	101.4
Total	**512**	**114.0**	**105**	**110.6**	**113**	**116.5**	**90**	**123.3**
Place of residence								
Local (Potter & Randall Counties)	370	72.7	348	81.7	22	22.2	11	14.9
All Panhandle Counties	45	8.8	34	8.0	12	12.1	7	9.4
Other Texas	31	6.1	13	3.0	19	19.2	14	18.9
Out of state	59	11.6	29	6.8	42	42.4	38	51.4
Unknown	4	0.8	2	0.5	4	4.1	4	5.4
Total	**509**	**100.0**	**426**	**100.0**	**99**	**100.0**	**74**	**100.0**

* Totals greater than 100 percent due to the multiple response nature of the question

Source: Texas Transportation Institute survey conducted January 11-13, 2005

anticipated, most tractor-trailer drivers were on the road as part of their job (98 percent), and of these, 74 (76.3 percent) said they were driving through the area while 39 (40.2 percent) were making deliveries in the local area. The majority of the tractor-trailer drivers were from out of state (42.4 percent), local counties (22.2 percent), and other Texas counties (19.2 percent).

Tractor-trailer drivers who were driving through the area as a part of their job are referred to as the “through tractor-trailer” group (n=74). Slightly more than one-half of these drivers (59.5 percent) were considered frequent road users; some said they were making deliveries in the local area (21.9 percent). Most through tractor-trailer drivers were from out of state (51.4 percent) or other Texas counties (18.9 percent), and another 14.9 percent were from counties in the local area.

Respondents were asked if they had previously seen DMS messages while driving on the roadway, and if so, how often they read the posted messages and how accurate they considered the information. Respondents were asked to rank the importance of information displayed on DMSs and were also presented a hypothetical situation and asked to select what action they would take when learning of lane closures due to roadway construction or an accident.

An overwhelmingly majority of all respondents (94.7 percent) indicated seeing DMS messages while traveling on the roadway of interest. There were little differences in the response distributions between the three road user groups. However, regular road users indicated that they had previously viewed DMS messages during their travels on the roadway 96.9 percent of the time (see Table 7). Seven out of 10 (71 percent) of the respondents said that they always read the messages and information on the DMS, while 21.2 percent indicated that they usually read the message.

Among tractor-trailer drivers 80.9 percent said that they always read the information on the DMSs. The distribution increased to 82.9 percent among tractor-trailer drivers who were on the road as part of their job and were traveling through the area.

Table 7. Prior Observation of DMS Messages.

	Respondent Type							
	All Respondents		Regular Road Users*		All Tractor-Trailers		Through Tractor-Trailers	
Previously Viewed DMS Messages	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Yes	482	94.7	413	96.9	94	94.9	70	94.6
No	27	5.3	13	3.1	5	5.1	4	5.4
Total	**509**	**100.0**	**426**	**100.0**	**99**	**100.0**	**74**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted January 11-13, 2005

Respondents were asked to rate the accuracy of the information posted on the electronic message signs. The majority of respondents considered DMS messages to be accurate most of the time (83.0 percent), while 16.4 percent considered them accurate some of the time.

Respondents were asked about the importance of information displayed on electronic message signs, and among all road user groups, accident and/or road hazard information ranked highest followed by weather-related advisory information, road closure and/or detour information, construction or maintenance, and public service or safety information (see Table 8).

Table 8. Most Important Message Information.

	Respondent Type							
	All Respondents		Regular Road Users		All Tractor-Trailers		Through Tractor-Trailers	
Information Type	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Weather-related advisory	4.63	0.86	4.62	0.88	4.76	0.69	4.77	0.71
Accident and/or road hazard warning	4.77	0.60	4.77	0.60	4.85	0.60	4.81	0.60
Construction or maintenance	4.45	0.88	4.46	0.88	4.32	0.88	4.32	0.88
Road closure and/or detour	4.55	0.87	4.56	0.87	4.59	0.87	4.57	0.87
Public service or safety*	3.59	1.49	3.64	1.49	3.64	1.49	3.65	1.49

* AMBER Alert sometimes used as an example of public service

Source: Texas Transportation Institute survey conducted January 11-13, 2005

Respondents were asked to choose among several possible options if faced with hypothetical situations while traveling on the roadway of interest. Respondents were told that the road was dry and traffic appeared to be about the same as usual and that there were two exits about 3 miles from where they planned on leaving the freeway. If respondents typically drove a car, pickup, or SUV, the surveyor pointed to a car in the picture. If respondents usually drove a tractor-trailer, the surveyor pointed to a truck on the picture.

Approximately one-half of all respondents were shown signs with messages about road construction and one-half shown signs with messages about an accident. An alternative message indicated that the left two lanes would be closed and to expect delays. Respondents were asked, "If you were faced with the specific conditions described and pictured on the card I'll show you, what would you do?" Most respondents indicated that they would respond in some way when seeing a DMS message about construction or accident delays (96.3 percent). The most frequent response to both accident and construction messages was to move to the right lane and continue on to their planned exit (see Table 9).

Table 9. Response to DMS Message, All Respondents.

	Shown "Accident" DMS		**Shown "Construction" DMS**		**Combined**	
Option	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Stay in your lane and continue on to planned exit	6	2.3	13	5.2	19	3.7
Move to the right lane and continue on to your planned exit	116	45.1	157	62.8	273	53.8
Exit the freeway at the next available exit and then continue on the frontage road	77	30.0	54	21.6	131	25.8
Exit the freeway at the next exit and choose another route (not on the frontage road) to your destination	58	22.6	26	10.4	84	16.7
Total	**257**	**100.0**	**250**	**100.0**	**507**	**100.0**

Source: Texas Transportation Institute survey conducted January 11-13, 2005

All respondents were more likely to exit the freeway due to delays caused by accidents (52.6 percent) compared to delays due to roadway construction (32.0 percent). There were differences in terms of what drivers would do once they exited the freeway. Respondents shown the accident DMS message were twice as likely to exit the freeway at the next exit and choose another route (not the frontage road) to their final destination compared to those shown a construction DMS message (22.6 percent compared to 10.4 percent). Fewer motorists would move to the right and continue on to their planned exit when shown an accident DMS message compared to a construction DMS message (45.1 percent versus 62.8 percent).

Demographic data collected during the survey include age, gender, and educational level of the respondent and are presented graphically in the following figures and tables. Among all survey respondents, 68.6 percent were between the ages of 26 and 65 years. The majority of survey respondents were male (58.2 percent), and an equal percentage had a high school education and some college (40.1 percent). Tractor-trailer drivers tend to be older and male but have similar education levels compared to all survey respondents.

The survey was intended to determine motorists' response to different messages displayed on DMSs and the potential of these messages to influence motorists' travel decisions.

The majority of the survey respondents were motorists who frequently traveled I-27 and I-40 in Amarillo, Texas, in a car, pickup truck, or SUV (78.4 percent) or a tractor-trailer or other large commercial truck (19.4 percent). Most of the trips were work or school related (46.2 percent), local trips (36.3 percent), and as part of the job (28.1 percent). Those traveling as part of their jobs were driving through the area (74.8 percent) and/or making local deliveries (39.2 percent). The majority of respondents were from local counties (72.7 percent), out of state (11.6 percent), and surrounding counties (8.8 percent).

An overwhelmingly majority of survey respondents (94.7 percent) indicated seeing DMS messages, and most said that they always read the messages (71 percent). A higher proportion of regular road users indicated seeing DMS messages (96.9 percent), and tractor-trailer drivers were more likely to always read the information of the DMS (80.9 percent). In terms of message content, respondents indicated that accident and road hazard information was of high importance, followed by weather-related advisory information.

Most respondents indicated that they would respond in some way when seeing a DMS message about construction or accident delays (96.3 percent). The most frequent response to both messages was to move to the right lane and continue on to their planned exit. Respondents were more likely to exit the freeway due to delays caused by accidents (52.6 percent) compared to delays due to construction (32 percent). Respondents shown the accident DMS message were twice as likely to exit the freeway at the next exit and choose an alternate route to their final destination compared to respondents shown the construction DMS message (22.6 percent compared to 10.4 percent).

Simulation Modeling

Traffic simulation models play an important role in mobility assessments of DMSs. They have been found effective in evaluating ATIS. They can also evaluate the performance of existing DMS systems and predict the expected benefits of future DMS installations. The primary advantage of using traffic simulation is that the expected operational benefit of a DMS can be estimated for any combination of traffic, roadway conditions, and incident situations that are rarely encountered and, therefore, very difficult to observe in the field. At locations where the detectors and sensor required to collect system-wide before and after study data for evaluating DMS effectiveness are missing, a properly calibrated traffic simulation may be the only means of reliably estimating the effect of DMS messages on traffic operations on the entire freeway arterial network. The run time required for simulating multiple scenarios (i.e., combinations of different traffic demands, incident durations, and variations in traffic control strategies) is much shorter than the time required for the field observation of a single event.

Available traffic simulation models are primarily suited for situations when DMSs are used for providing real-time information to motorists. For example, the operational and environmental effects of a DMS message that encourages traffic diversion to an alternate route can be modeled using several microscopic traffic simulation models (i.e., CORSIM, VISSIM, INTEGRATION, PARAMICS, AIMSUN, and MITSIM). The evaluation of the effectiveness of a DMS message about future changes in traffic control is a more complex task because advance information is typically disseminated through several different channels, and the contribution of different information sources to the entire system benefit is very difficult to estimate.

VISSIM is a microscopic, behavior-based multimodal traffic simulation model. It was developed by PTV AG in Karlsruhe, Germany, and has also been widely used in the United States. It is capable of modeling traffic and public transport operations in a network integrating street and freeway systems. The program can analyze traffic operations under constraints such as different lane configurations, traffic compositions, traffic signals, etc., thus making it a useful tool for the evaluation of various traffic control alternatives based on MOEs such as delay, queue length, and throughput. With its dynamic assignment model, VISSIM can also answer route choice dependent questions such as the impacts of variable message signs or the potential for traffic diversion into neighborhoods for networks up to the size of medium-sized cities. One of the unique features of VISSIM is the VAP language module. It allows the user to externally control vehicle detection, traffic control, and driver-behavior logic. The VAP language module makes it possible to model and evaluate the effectiveness of various ITS applications such as variable message signs and traffic diversion.

In many areas where the freeway is connected to a relatively low-volume and high-capacity roadway network, it is reasonable to assume that the portion of traffic diverting from the congested freeway, in response to DMS messages, will not exceed the capacity of the alternate route and, therefore, will cause no further delay. This would be the situation as exists in the Amarillo ITS corridor. In such cases, it may be sufficient to only consider the changes in freeway traffic in order to evaluate the effectiveness of DMS messages. This type of evaluation is referred to as "freeway-level DMS evaluation." The following data are required for setting up a simulation model for evaluating DMS effectiveness:

- Geometric data—Number of lanes, lane widths, location of lane additions/drops, grade levels, and entry/exit ramp locations have to be specified for the entire network.
- Speed data—Speed limits and/or free-flow speeds are needed for all roadway sections.
- Volume data—Traffic volume data are needed at each point where vehicles can enter the network.

- Incident data—These data evaluate the time of onset, duration, location, affected roadway length, and the number of lanes closed and/or affected.
- Traffic control—Stop or yield signs for signalized intersections (if there are any along the diversion route), signal phases, timing plans, detector locations, and lane configurations have to be specified.

Another critical model input is the percentage of traffic diverting in response to warning messages displayed on DMSs, which may be determined from field observations, estimated from surveys, or predicted from a route choice model that was derived from previous observations. Although route choice models are useful tools, they are fairly site specific and are sensitive to changes in driver characteristics. To determine traffic diversion from field observations, traffic counts have to be taken on the main lane and exit ramp, or in two locations on the main lane immediately upstream and downstream of the diversion point. The traffic counts can be obtained by installing loop detectors, tubes, video detection, or any other vehicle detection technology that can record time-stamped volume data.

If field observations are not available, as is the case in Amarillo, surveys may be conducted to assess the drivers' preference, or at least stated preference, with regard to their expected travel behavior in response to various DMS messages. The survey results can be used directly or in conjunction with field observations (vehicle counts) to estimate the percentage of diverting traffic in response to different DMS messages under various roadway and traffic conditions. For the Amarillo DMS corridor evaluation, based upon limitations to available data, a survey was conducted of motorists to allow an estimate of the percentage of traffic diversion under commonly encountered incident conditions for which advisement messages would be displayed on DMSs.

There are five DMSs in Amarillo. Three of them are on I-40, and the other two are on I-27 and US 87/287. This study focuses on the DMSs on I-40 only. Figure 9 shows the study area. Two of the DMSs are located west of the I-40 and I-27 interchange, and one DMS is deployed east of the interchange, as shown in the figure. DMS 1 located at I-40 and Dowell Road, and DMS 2 located at I-40 and Coulter Road may be used to display travel information for motorists traveling in the

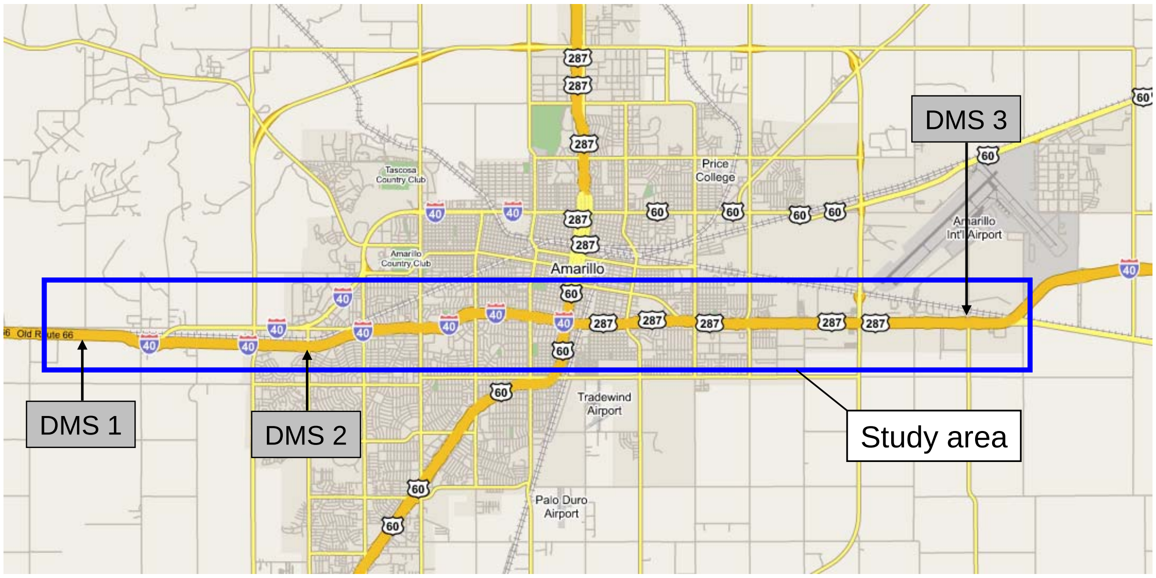
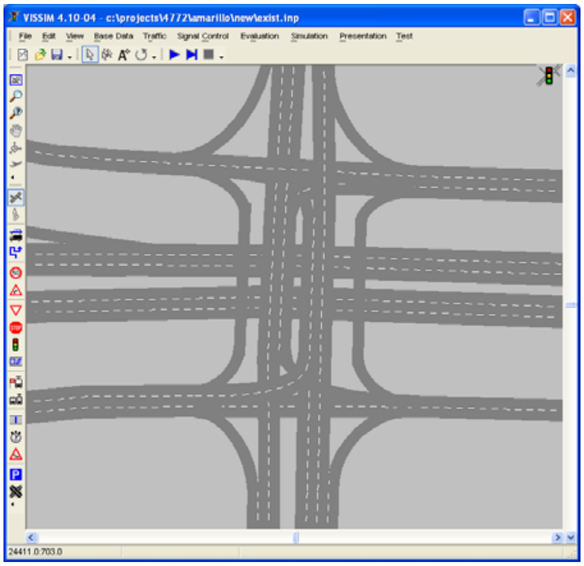


Figure 9. Modeling Study Area.

eastbound direction on I-40. DMS 3 located at I-40 and Pullman Road can be used to inform drivers traveling in the westbound direction on I-40. Boundaries of the modeling study were delineated based on the estimated influence area of these DMSs. They are indicated by a box in Figure 9. It is assumed that traffic operations outside of this boundary will not be affected significantly by DMS messages. The modeling area includes an approximately 17-mile segment of the I-40 corridor. The western boundary of the modeling area is about 0.65 miles west of Dowell Road, and the eastern boundary is about 0.6 miles east of Pullman Road. Therefore, motorists entering the I-40 corridor either from the east or west travel have to travel at least 0.6 miles before they would see any DMS messages. The network also includes the I-40 and I-27 interchange and the frontage road system in both directions. Along the frontage roads, there are 20 diamond interchanges with 26 (2 X 13) signalized intersections at major connecting arterials and 14 (2 X 7) stop-controlled intersections.

To faithfully replicate traffic operations on a roadway network under various traffic and roadway conditions and assess the impact of different incident scenarios and traffic control strategies, an accurate model of the roadway system is required. Different simulation models may use different network representations. The basic element of a roadway network in VISSIM is a link representing a roadway segment with the appropriate number of lanes and specified direction of flow. The flow of traffic between links is provided by connectors. To create an accurate VISSIM network (i.e., link-connector diagram) at least a scaled map of the study area is required. If provided in electronic format, it may be used as a background for drawing the links over the actual roadway system. It assures a correct horizontal roadway alignment (e.g., curvature, locations of intersections, ramps, and other roadway elements). However, maps typically do not provide information on the number of lanes, intersection configuration, location of signals and traffic control devices, and other roadway design elements. These data may be taken for example from "as-built" plans (computer-aided design [CAD] drawings) and up-to-date high-resolution aerial photographs or satellite images. Aerial photos of sufficiently good resolution are available free of charge from www.terraserver-usa.com and from Google Earth (http://earth.google.com). They can be downloaded and saved as JPG image files. For example, an aerial photo of the diamond interchange at I-40 and Georgia Street in Amarillo is shown in Figure 10. Such image files make it relatively easy to identify direction of traffic, number of lanes, lane drops, lane merges, type of intersection control (e.g., signal or stop control), location of signal heads and stop lines, bays for exclusive right or left turns, and pavement markings indicating permitted vehicle movements. However, images of sufficiently high resolution may cover only a small portion of the desired study area. To cover the entire area of a relatively large roadway system, multiple overlapping images can be downloaded and then stitched together using some image-processing software. This approach is illustrated in Figure 10 using four overlapping images. The images were downloaded from www.terraserver-usa.com and stitched using Canon Utilities PhotoStitch Version 3.1. Note that these images do not show as much detail as the aerial photo in Figure 10. For large networks, it may often be necessary to use images of somewhat lower resolutions to keep the image file size manageable. Although high-resolution images show more details of the roadway system, for large complex networks, such as the Amarillo case study, the file size of stitched images may become excessively large and difficult to use for network editing in the simulation model. Therefore, selection of the most appropriate image resolution is a compromise between desired level of detail of the roadway system and image file size.

Normal View of VISSIM Network



Centerline View of VISSIM Network

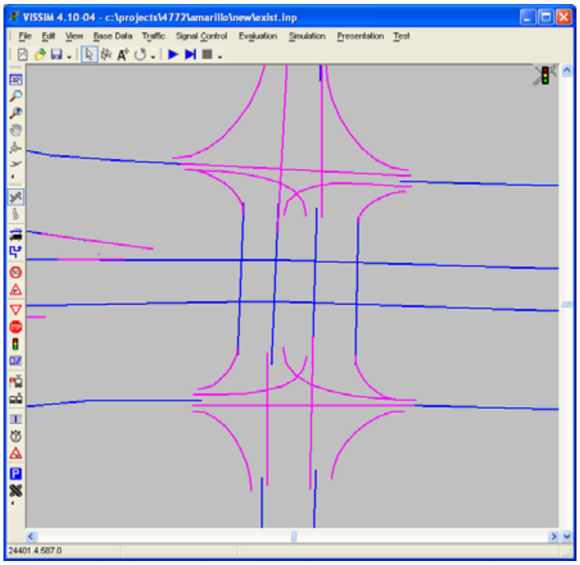


Figure 10. Aerial Photo and VISSIM Network for I-40 and Georgia Street in Amarillo, Texas.

Vehicles can enter and exit the network at multiple points along the network boundary. The Amarillo network has 47 entry points. At each entry point, the flow rate of entering traffic has to be specified. It can be time variable or constant volume given in vehicles/hour. Researchers assumed that vehicles enter the system according to a Poisson distribution (random arrival) with an expected arrival rate determined by the specified flow rate at each entry point.

To evaluate the operational impact of an incident and assess the effectiveness of DMS messages, the actual traffic volumes observed at each entry point during the incident are needed. However, these data were not available. Only AADT data were available for certain segments of I-40 and its frontage roads. They were given for main lane and frontage road segments between exit and entry ramp locations. Researchers decided that DHV that can be determined from the AADT data would be used to estimate flow rates for the vehicle entry points.

DHV for both eastbound and westbound directions was determined using the following relationships:

$DHV_E = (K/100)\ (D_E/100)\ AADT$ $\qquad$ $DHV_W = (K/100)\ (D_W/100)\ AADT$

where the K factor represents the percent of AADT that occurs in the 30th highest hourly volume, and the D_E and D_W factors are the percents of traffic flowing in the eastbound and westbound directions.

The directional factors for I-40 in Amarillo were given as D_E=54 percent and D_W=46 percent. The K factor was determined using data from two permanent ATR locations, stations S-120 and S-218 in Amarillo, Texas. The K factors for the two stations are shown in Table 10. The average of these two values, K=10.2 percent, was used in estimating the design hourly volumes DHV_E and DHV_W.

Table 10. K Factors for 30th Highest Hourly Volume at ATR Stations in Amarillo, Texas.

Station	Location	K Factor (%)
S-120	US 287, 2.5 miles east of I-40	11.7 percent
S-218	I-40, 0.4 miles E of US 287	8.6 percent

The available AADT and calculated DHV data are given in Tables 11 and 12. From these DHV data, volumes on the exit and entry ramps and on the connecting arterials were estimated using the conservation of flow concept; i.e., the total flow in links directed toward a node, plus the supply at the node, minus the demand at the node, equals the total flow in all links directed away from the node. Vehicle supply and demand is equal to zero in each node except at the entry and exit points. Although the approach is straightforward, some missing AADT and DHV data required some approximations in the form of linear interpolations.

Different vehicle compositions and desired speed distributions can be specified for vehicles entering the network at any entry point. Desired speed distributions can be selected from a predefined menu or created based on empirical data. A new desired speed distribution can be created by specifying the minimum and maximum speeds and manually inserting some intermediate points of the cumulative speed distribution function. Ideally, both vehicle composition and desired speed distribution should be determined from observed vehicle counts and speeds under free-flow conditions at the vehicle entry points. Availability of this data for at least freeway entry points is desirable because they have a significant effect on travel times, delays, and other MOEs. The truck percentages and desired speed distributions used at the vehicle entry points of the Amarillo network are shown in Figure 11.

Once a vehicle enters the network, its desired speed will not change until it enters a *reduced speed area* or another roadway facility with a different speed limit. Reduced speed areas can be used for temporary speed changes. They are typically short sections with slow speed characteristics (i.e., horizontal curves with relatively small radii or turning movements at intersections). Upon arriving at a reduced speed area, vehicles are assigned a new lower desired speed pulled from the desired speed distribution defined for that particular roadway section.

Table 11. Mainline and Frontage Road ADTs and DHVs for I-40 Eastbound.

Mile Point	Length of Section	Mainline ADT (Vehicles/ Day)	Frontage Road ADT (Vehicles/ Day)	Frontage Road Lanes	Main Lanes	Mainline DHV (Vehicles/ Hour)	Frontage Road DHV (Vehicles/ Hour)	Road
1	1.272	12,610	0	2	2	695	0	
2.272	0.694	12,610	120	2	2	695	7	exit to Rest Area
2.966	0.009	12,610	120	2	2	695	7	enter from Rest Area
2.975	0.401	12,610	120	2	2	695	7	exit to Adkisson
3.376	0.397	12,610	120	2	2	695	7	enter from Adkisson
3.773	0.589	12,610	120	2	2	695	7	exit to RM 2381
4.362	2.376	12,310	390	2	2	678	21	enter from RM 2381
6.738	0.472	12,310	390	2	2	678	21	exit to Arnot
7.21	2.445	17,750	210	2	2	978	12	enter from Arnot
9.655	0.795	17,750	210	2	2	978	12	exit to Hope
10.45	1.32	17,750	210	2	2	978	12	exit to Business I-40
11.77	0.828	17,750 18,690	210 570	2	2	978 1029	11 31	enter from Daland
12.598	0.575	18,690	570	2	2	1029	31	exit to Soncy
13.173	0.437	65,440	4830	2	3	3604	266	enter from Soncy
13.61	0.492	65,440	4830	2	3	3604	266	exit to Coulter
14.102	0.5	65,440	4830	2	3	3604	266	enter from Coulter
14.602	0.668	65,440	4830	2	3	3604	266	exit to Bell
15.27	0.482	83,580	2150	2	3	4604	118	enter from Bell
15.752	0.388	83,580	2150	2	3	4604	118	exit to Western
16.14	0.12	83,580	2150	2	3	4604	118	enter from Western
16.26	0.55	83,580	2150	2	3	4604	118	exit to Paramount
16.81	0.549	83,580	2150	2	3	4604	118	enter from Paramount
17.359	0.303	82,770	3570	2	3	4559	197	exit to Georgia
17.662	0.151	82,770	3570	2	3	4559	197	enter from Georgia
17.813	0.405	82,770	3570	2	3	4559	197	enter from W. 19th
18.218	0.003	82,770	3570	2	3	4559	197	exit to Washington
18.221	0.282	82,770	3570	2	3	4559	197	enter from Washington
18.503	0.274	62,500	99	2	3	3443	5	exit to US 60 & I-27
18.777	0.126	92,710	99	2	3	5106	5	enter from US 60 & I-27
18.903	0.548	92,710	99	2	3	5106	5	enter from US 60 & I-27
19.451	1.198	71,850	12000	2	3	3957	661	exit to Ross Street

Table 11. Mainline and Frontage Road ADTs and DHVs for I-40 Eastbound (Continued).

Mile Point	Length of Section	Mainline ADT (Vehicles/ Day)	Frontage Road ADT (Vehicles/ Day)	Frontage Road Lanes	Main Lanes	Mainline DHV (Vehicles/ Hour)	Frontage Road DHV (Vehicles/ Hour)	Road
20.649	0.186	57,460	12650	2	3	3165	697	enter from Ross Street
20.835	0.899	57,460	12650	2	3	3165	697	exit to Nelson
21.734	0.544	57,460	12650	2	3	3165	697	enter from Nelson
22.278	0.552	58,710	1260	2	3	3234	69	exit to Grand
22.83	0.468	58,710	1260	2	3	3234	69	enter from Grand
23.298	0.506	49,200	5380	2	3	2710	296	exit to Eastern
23.804	0.456	49,200	5380	2	3	2710	296	enter from Eastern
24.26	0.242	47,810	910	2	3	2633	50	exit to Whitaker
24.502	0.888	47,810	910	2	3	2633	50	enter from Whitaker
25.39	0.4	40,700	320	2	3	2242	18	exit to Lakeside
25.79	0.548	40,700	320	2	3	2242	18	exit to Pullman
26.338		33,960	130	2	3	1871	7	enter from Pullman

Table 12. Mainline and Frontage Road ADT and DHV Points for I-40 Westbound.

Mile Point	Length of Section	Mainline ADT (Vehicles/ Day)	Frontage Road ADT (Vehicles/ Day)	Frontage Road Lanes	Main Lanes	Mainline DHV (Vehicles/ Hour)	Frontage Road DHV (Vehicles/ Hour)	Road
31.108	4.77	33,960	0	1	2	1593	0	
26.338	0.548	33,960	30	2	3	1593	1	exit to Pullman Road
25.79	0.4	40,700	540	2	3	1910	25	enter from Pullman Road
25.39	1.105	40,700	540	2	3	1910	25	exit to Lakeside
24.285	0.43	47,810	1430	2	3	2243	67	enter from Lakeside
23.855	0.432	49,200	4410	2	3	2308	207	exit to Whitaker
23.423	0.653	49,200	4410	2	3	2308	207	enter from Whitaker
22.77	0.492	58,710	1560	2	3	2755	73	exit to Eastern
22.278	0.532	58,710	1560	2	3	2755	73	enter from Eastern
21.746	0.808	57,460	9100	2	3	2696	427	exit to Grand
20.938	0.282	57,460	9100	2	3	2696	427	exit to Business US 287
20.656	1.205	57,460	9100	2	3	2696	427	enter from Business US 287
19.451	0.572	71,850	11060	2	3	3371	519	enter from Nelson
18.879	0.292	92,710	99	2	3	4350	5	exit to Ross

Table 12. Mainline and Frontage Road ADT and DHV Points for I-40 Westbound (Continued).

Mile Point	Length of Section	Mainline ADT (Vehicles/ Day)	Frontage Road ADT (Vehicles/ Day)	Frontage Road Lanes	Main Lanes	Mainline DHV (Vehicles/ Hour)	Frontage Road DHV (Vehicles/ Hour)	Road
18.587	0.074	62,500	29	2	3	2933	1	enter from Ross
18.513	0.295	62,500	29	2	3	2933	1	exit to I-27 & US 60
18.218	0.054	82,770	1540	2	3	3884	72	enter from I-27 & US 60
18.164	0.351	82,770	1540	2	3	3884	72	enter from I-27 & US 60
17.813	0.151	82,770	1540	2	3	3884	72	exit to Washington
17.662	0.256	82,770	1540	2	3	3884	72	enter from Washington
17.406	0.586	82,770	1540	2	3	3884	72	exit to Crockett
16.82	0.48	83,580	1760	2	3	3922	83	exit to Georgia
16.34	0.158	83,580	1760	2	3	3922	83	exit to Paramount
16.182	0.522	83,580	1760	2	3	3922	83	enter from Georgia
15.66	0.41	83,580	1760	2	3	3922	83	enter from Paramount
15.25	0.742	83,580	1760	2	3	3922	83	exit to Western
14.508	0.248	65,440	3300	2	3	3070	155	enter from Western
14.26	0.65	65,440	3300	2	3	3070	155	exit to Bell
13.61	0.437	65,440	3300	2	3	3070	155	enter from Bell
13.173	0.575	65,440	3300	2	3	3070	155	exit to Coulter
12.598	0.848	18,690	230	2	2	877	11	enter from Coulter
11.75	1.36	17,750 18,690	230 410	2	2	877 833	11 19	exit to Soncy
10.39	0.764	17,750	410	2	2	833	19	enter from Soncy
9.626	2.266	17,750	410	2	2	833	19	exit to Business I-40
7.36	0.817	17,750	410	2	2	833	19	enter from Business I-40
6.543	1.466	12,310	120	2	2	578	6	exit to Arnot
5.077	0.414	12,310	120	2	2	578	6	enter from Arnot
4.663	0.413	12,310	120	2	2	578	6	exit to RM 2381
4.25	0.431	12,310	120	2	2	578	6	enter from RM 2381
3.819	1.547	12,610	100	2	2	592	5	exit to Adkisson
2.272		12,610	100	2	2	592	5	enter from Adkisson

FREEWAY

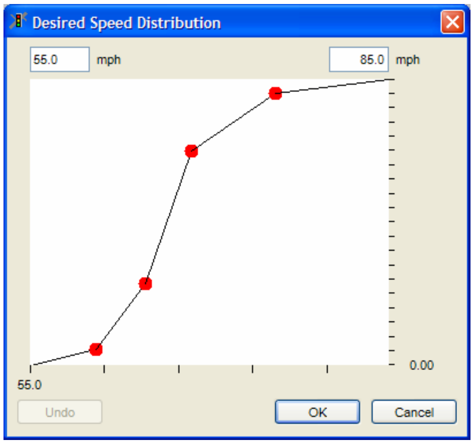
Passenger car: 85%

Truck: 15%

Minimum speed: 55 mph

Maximum speed: 85 mph

Desired Speed Distribution


55.0 mph
85.0 mph

FRONTAGE ROAD

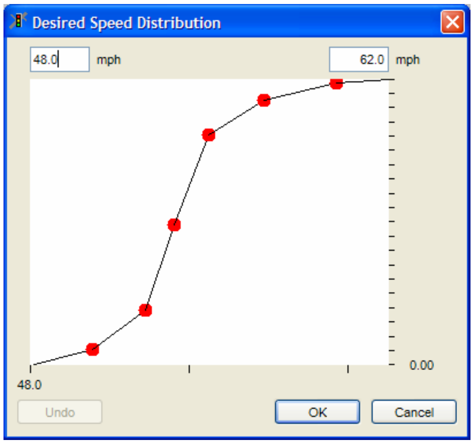
Passenger car: 96%

Truck: 4%

Minimum speed: 48 mph

Maximum speed: 62 mph

Desired Speed Distribution


48.0 mph
62.0 mph

FRONTAGE ROAD

Passenger car: 98%

Truck: 2%

Minimum speed: 30 mph

Maximum speed: 40 mph

Desired Speed Distribution

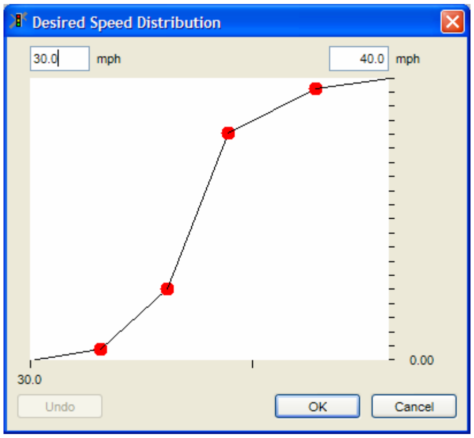

30.0 mph
40.0 mph

Figure 11. Vehicle Compositions and Desired Speed Distributions.

After leaving the reduced speed area, vehicles are reassigned their original desired speed. In case of a permanent speed change (e.g., when a vehicle turns from an arterial to the frontage road where the speed limit is higher), a new *desired speed decision* is implemented and remains in effect until the vehicle passes another desired speed decision point in the network. There are only a few reduced speed areas (e.g., at the I-40 and I-27 interchange) but numerous desired speed decision points in the Amarillo network.

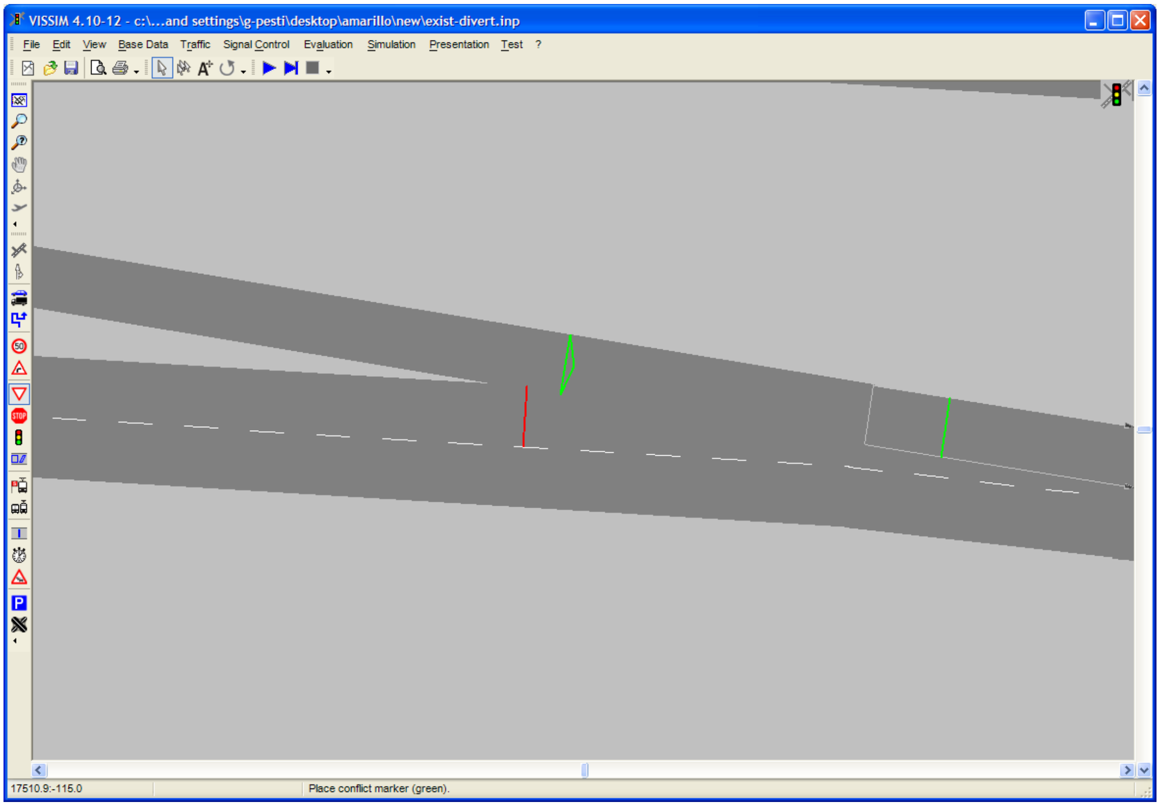
Vehicles entering the system at any entry point (origin) may leave the network at any exit point (destination). The sequence of links and connectors between the origin and destination specifies a route. A route can have any length, and routes from a single origin can branch out into multiple destinations. An origin can also be considered as a routing decision point, where drivers make decisions on what route to take. A routing decision can be defined by the route itself and the proportion of vehicles taking that specific route from the origin. Although these data are essential, reliable estimates for the routing decisions are probably the most difficult to provide. There are methods for estimating origin-destination (O-D) demands, but they typically are data intensive. For example, a study conducted in Minnesota used zone-to-zone traffic flows from a transportation planning model and observed flows on entry and exit ramps to estimate the O-D demand. Note that ramp flow data may also be useful in estimating traffic diversions from congested freeways during incident situations.

The Amarillo network has more than 50 routing decisions. In the absence of adequate data, the relative flows in the routing decisions are hypothetical, although they were estimated with considerations to the design hour volumes in Tables 11 and 12.

Conflicting movements may occur at numerous locations in the network (e.g., merging traffic non-signalized and signalized intersections). *Priority rules* are used to designate the right-of-way to certain movements. A priority rule is defined by a stop line and at least one conflict area. Figure 12 shows one of the exit ramps in the Amarillo network. The exit ramp traffic merges with the left-lane traffic on the frontage road. The red stop line indicates the location where yielding vehicles have to stop. The two green conflict markers specify the boundaries of the conflict area. A priority rule can be defined by specifying the length of the conflict area (minimum distance headway) and the minimum gap time. The frontage road traffic is required to yield if there is an exiting vehicle in the conflict area or the exiting vehicle's travel time to the second conflict marker is shorter than the specified minimum headway.

Multiple priority rules can be applied to the same stop line. It is particularly useful for non-signalized or signalized intersections where a vehicle movement can coincide with several conflicting movements.

Modeling driver behavior in merge areas and weaving sections requires special attention. The roadway segment, where merge and weaving activity occurs, has to be represented by a separate link with the appropriate number of lanes (i.e., the number of lanes in the link upstream plus the number of merging lanes). Routing decisions cannot end in a merging (weaving link). Routing decisions originated upstream must have destinations in links downstream of the merging link. Finally, a merging link can have two or more connectors upstream and only one connector downstream.



Place conflict marker (green).

Figure 12. Priority Rule at an Exit Ramp in the Amarillo Network.

There are more than 30 merging sections in the Amarillo network, most of them located at the entry ramps. The appropriate length and number of lanes was determined for each section based on the aerial photo mentioned earlier.

Diamond interchanges consist of two intersections. They can either be stop-sign controlled or signalized intersections. Both types can be found in the Amarillo network. Interchanges closer to the network boundaries in both the eastbound and westbound directions, where traffic on the frontage roads and crossing roadways are relatively light, have stop-controlled intersections. At all other locations, the interchanges consist of pairs of signalized intersections. The following two sections provide a brief summary of how traffic is modeled at non-signalized and signalized intersections.

All non-signalized intersections in the Amarillo network are controlled by stop signs. Traffic on stop-controlled intersection approaches is modeled by a combination of stop signs and priority rules. Vehicles will stop at the stop sign location regardless of the presence of conflicting traffic. At the same time, the priority rules take care of providing the required minimum distance headway and time gap for the safe and orderly movement of conflicting traffic.

The Amarillo network includes interchanges with signalized intersections along the I-40 corridor. Figure 13 shows all traffic movements at a diamond interchange.

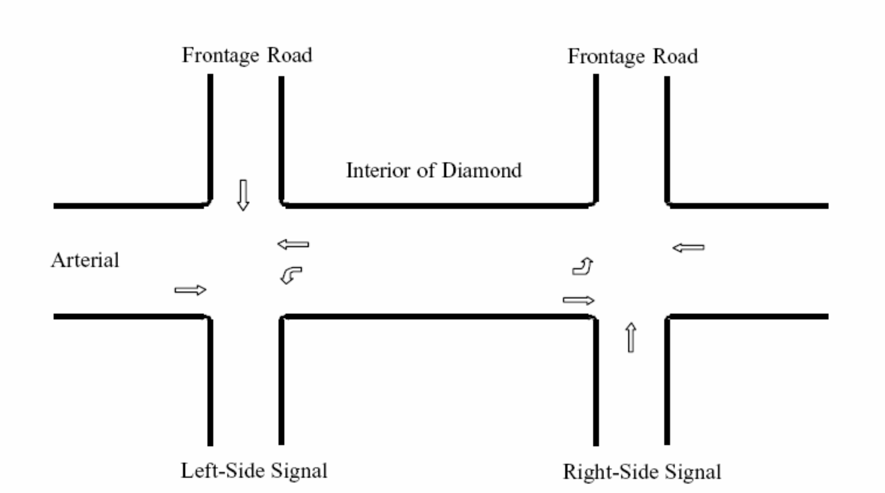


Figure 13. Movement at the Two Intersections of a Diamond Interchange.

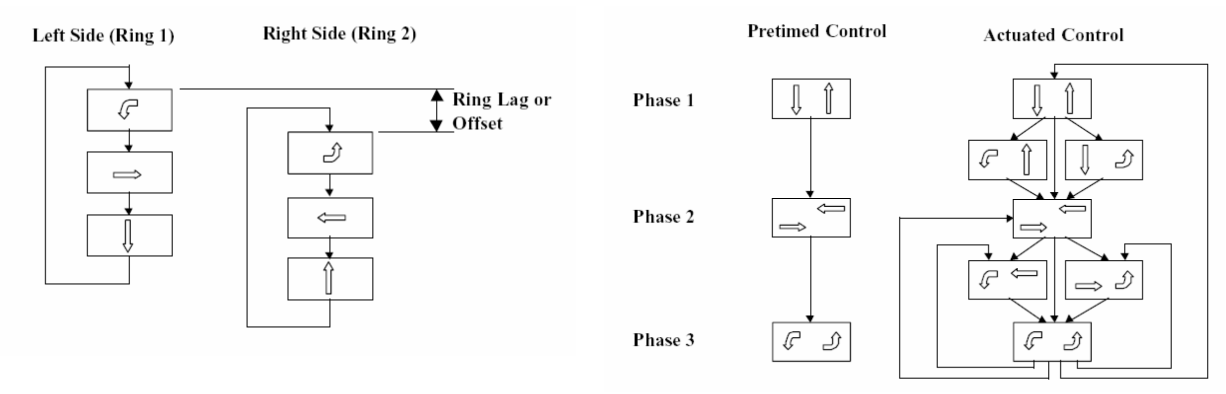
In Texas, signals at the two intersections are typically operated according to one of the following signal control strategies:

- separate intersection mode,
- Texas three-phase control strategy, and
- Texas four-phase control strategy.

Figure 14 shows the phase diagrams for the three controlled studies.

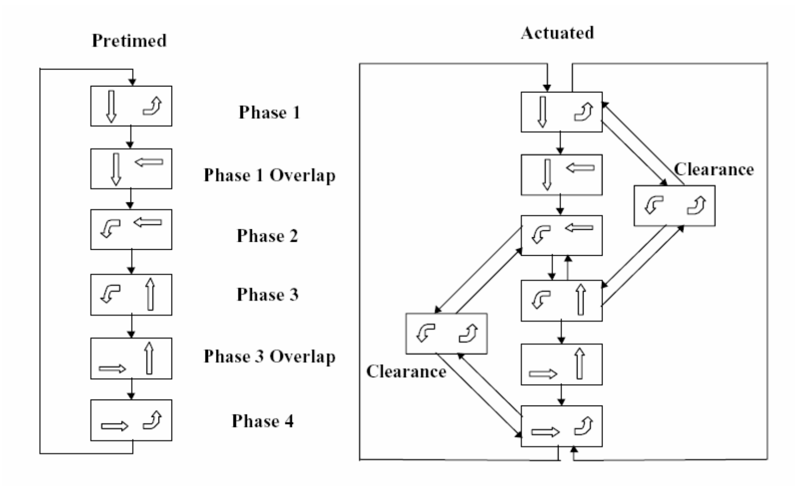
The separate intersection mode is illustrated in Figure 14(a). This type of control is commonly used when the distance between the two intersections is relatively long (i.e., greater than 400 feet). Typically, each intersection is controlled by a separate controller, although it can be implemented by a single controller as well. For the separate intersection mode, green times are calculated for each signal as for independent intersections along an arterial. However, the two controllers are interconnected, and the intersections are coordinated by using common cycle length and specifying an appropriate offset between them. This type of signal control strategy in actuated coordinated mode was used for all signals on the frontage roads. Signal pairs at each diamond interchange were coordinated to provide progression for the arterial through movements. Alternatively, the Texas three-phase (Figure 14[b]) or Texas four-phase (Figure 14[c]) may also be used, depending on which control was actually implemented during the time period of interest.

The Texas three-phase signal control strategy provides progression for the arterial through movements and works well when there is sufficient storage space between the two intersections and traffic demand on the frontage roads is well balanced. The use of an optimum cycle length is critical for good performance of this control type. It may be effectively used for intersection distances less than 400 feet and for light to moderate traffic demands if the interchange has U-turn bays and exclusive left-turn lanes. Several interchanges in the Amarillo network satisfy this condition.



A. Separate intersection mode

B. Texas three-phase control strategy



C. Texas four-phase control strategy

Figure 14. Typical Signal Control Strategies at Diamond Interchanges in Texas.

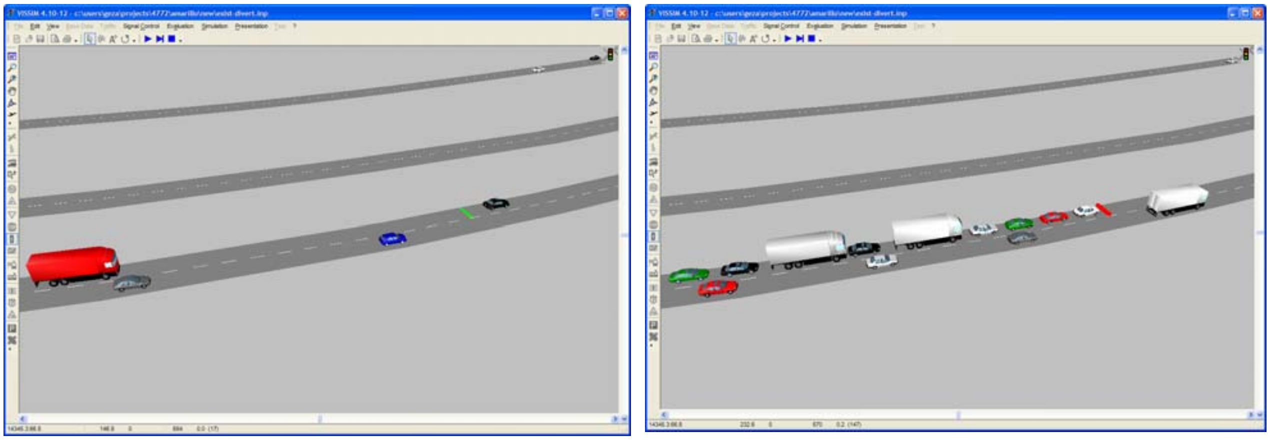
The Texas four-phase control strategy was developed to minimize internal queues (i.e., queues forming between the two intersections). It provides progression for arterial through movements by coordinating the two signals and accounting for the estimated internal travel time (internal offset). It typically works well when the distance between intersections is less than 400 feet. For effective operation, a long cycle length should be avoided. Researchers also recommended that

U-turn bays should be provided for sites with heavy U-turn demand and short intersection distances.

A traffic incident was modeled by placing a signal head at the incident location into each freeway lane that was blocked by the incident. The signal was red for the duration of the incident, and green at any other times during the simulation. It was controlled by a simple VAP script that was developed for this purpose. A text file (with .VAP extension), similar to the one shown below, was created for each virtual incident that was modeled in the Amarillo study:

```
PROGRAM Incident;
CONST
incidentBegin = 200, /* Time when incident occurs (seconds) */
incidentEnd = 500;   /* Time when incident is removed (seconds) */
SUBROUTINE incidentGenerator;
IF (simTimer >= incidentBegin) AND (simTimer <= incidentEnd) THEN
        Sg_red(1);ELSE
        Sg_green(1);END.
start(simTimer);
GOSUB incidentGenerator.
```

In this simple hypothetical example, an incident occurs 200 seconds after the simulation begins, and it blocks the entire left lane for 300 seconds (5 minutes). The two images in Figure 15 were captured at simulation times t_1=145 seconds and t_2=233 seconds from an actual simulation of this case. The left image shows that the signal is green, and traffic flows freely in both lanes. The right image shows that the left lane is blocked, and vehicles are queued in the left lane in advance of the red signal.



Time = 145 seconds

GREEN signal: No incident

Time = 233 seconds

RED signal: Incident blocking left lane

Figure 15. Incident Modeling Using VAP-Controlled Traffic Signal.

Two scenarios were considered for modeling traffic diversions during an incident. First motorists were not informed by DMS messages about the existence an incident or work zone lane closure and diverted only in response to the increased congestion that they observed on the freeway. In the second case, DMS messages were displayed during the time period of lane blockage to warn drivers of possible traffic congestion and delay ahead. Expected diversion percentages for both scenarios were estimated from motorist surveys previously discussed. In case of incidents, it was assumed that the diversion messages were activated immediately after the incident occurred and remained active for the entire duration of the incident. For work zone lane closures, the DMS message was displayed for the entire period of lane blockage. The following section briefly describes how traffic diversion to the frontage road was modeled.

When no DMS message was displayed, motorists began diverting only when they experienced a certain level of congestion. Congestion was monitored by placing virtual detectors in each freeway lane near the exit ramp, as shown in Figure 16. In addition, a detector was also placed on the exit ramp. For a multi-lane exit ramp, multiple detectors are needed, one for each lane. Let O_{F1}, O_{F2}, O_{F3}, and O_R denote the occupancies measured by the detectors in the three freeway lanes and on the ramp. Using these real-time occupancy data pulled from the simulation in each time step, traffic diversion was modeled according to logic of the following type:

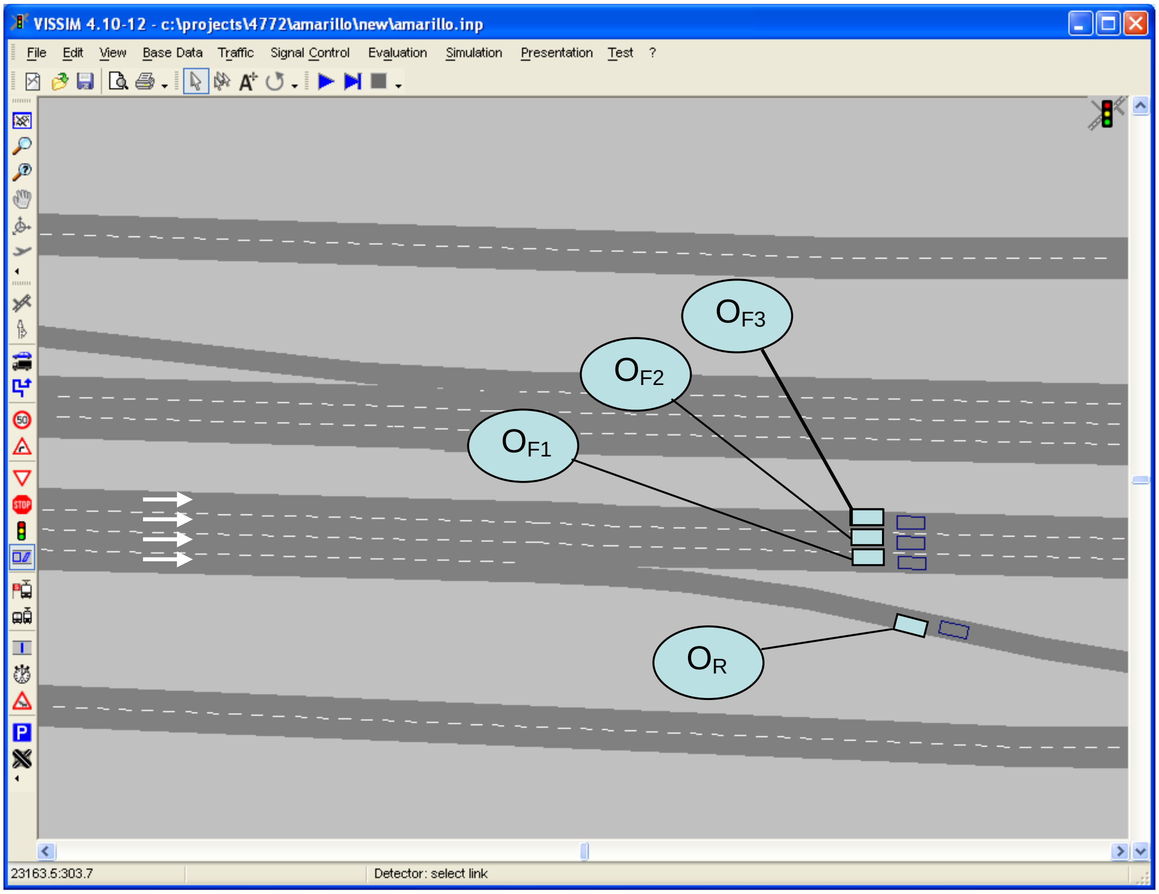


Figure 16. Traffic Diversion to the Frontage Road.

```
IF (AVERAGE ($O_{F1}$, $O_{F2}$, $O_{F3}$) > $O^*_F$) THEN
    IF ($O_R < O^*_R$) THEN
        Diversion % = $P_{CONGESTED}$
    ELSE
        Diversion % = $P_{NORMAL}$
    ENDIF
    ENDIF
```

Here O^*_F and O^*_R are different occupancy thresholds for the freeway and ramp. For example, in the simulations, researchers used O^*_F =50 percent and O^*_R =30 percent, but these thresholds need calibration. The percentages P_{NORMAL} and $P_{CONGESTED}$ correspond to the proportion of traffic typically exiting at the ramp under normal conditions and diverting under congested conditions. P_{NORMAL} can be determined from planning studies or field observations. $P_{CONGESTED}$

can be obtained, for example, from driver surveys, as it was done in this study. Please note that $P_{CONGESTED}$ corresponds to a situation when motorists are not informed by DMS messages. The incremental diversion percentage associated with a certain DMS message is to be added to $P_{CONGESTED}$ and P_{NORMAL} when the messages are displayed.

Besides diverting traffic, the traffic entering the freeway is also affected by the actual congestion levels on the freeway and frontage roads. If the freeway and entry ramp are congested but the frontage road is not, drivers may stay on the frontage road until the next entry ramp. Therefore, an additional rule, similar to the one above, was applied for determining the percentage of traffic entering the freeway. Application of this rule also requires the placement of virtual detectors in each lane of the frontage road and on the entry ramp.

To select typical DMS applications for the simulation study, the type and frequency of all DMS messages used during the period of 2003 through 2005 on the I-40 corridor were reviewed. The data were provided by Ms. Robin Frisk, manager of the PEGASIS Traffic Management Center in Amarillo. Only a few incident messages were available for the DMS at Coulter Road, and those incidents occurred 20 miles west of Amarillo, outside the simulation network. Therefore, they were not used for this modeling study. Tables 13 and 14 list the messages for the other two DMS locations. They are classified into three categories: construction, incident, and other messages.

Based on a review of the DMS messages, researchers found that most incidents and road constructions over the last 3 years involved either a single- or double-lane closure for shorter or longer periods of time. Therefore, simulations were conducted for both types of lane closure scenarios. A hypothetical incident (or short construction zone) was created between Olsen Boulevard and Western Street on I-40 eastbound. It is a three-lane section of the freeway located about 7 miles downstream of the DMS at Dowell Road. There are four exit ramps between the DMS and the incident location that can be used by motorists to divert to the frontage road and use it as a potential alternate route during congestion.

Table 13. Content, Frequency, and Duration of DMS Messages at Pullman.

DMS	Year	Message	Frequency	Duration (seconds)		
				Average	Minimum	Maximum
CONSTRUCTION						
Pullman	2003	I27 south road construction one lane traffic follow detour	2	897442.5	679569	1115316
Pullman	2003	I40 west detour 16 miles ahead merge right follow detour exit 62A	1	7761	7761	7761
Pullman	2003	I40 west rt lanes closed 10 miles ahead I40 west georgia st exit closed	1	21882	21882	21882
Pullman	2003	bridge construction 10 miles ahead lanes closed expect delays	2	10537.5	3037	18038
Pullman	2003	bridge construction 10 miles ahead lanes closed merge right follow detour	1	28850	28850	28850
Pullman	2003	bridge construction 7 miles ahead lanes closed expect delays	2	4125	3189	5061
Pullman	2003	bridge construction 8 miles ahead	1	531671	531671	531671
Pullman	2003	bridge construction 8 miles ahead lanes closed detour ahead merge right	1	140476	140476	140476
Pullman	2003	bridge construction 8 miles ahead right lane closed merge left	1	8664	8664	8664
Pullman	2003	bridge construction I40/washington lanes closed 8 miles ahead merge right	2	5056619	126084	9987154
Pullman	2003	road construction 10 miles ahead left lane closed expect delays	1	1035	1035	1035
Pullman	2003	road construction 10 miles ahead left two lanes closed expect delays	4	30051.75	28848	32761
Pullman	2003	road construction 12 miles ahead left two lanes closed expect delays	1	518711	518711	518711
Pullman	2003	road construction 7 miles ahead left lane closed expect delays	3	9834.333333	4491	17606
Pullman	2003	road construction 7 miles ahead left two lanes closed expect delays	3	22010.66667	306	35980
Pullman	2003	road construction 9 miles ahead left two lanes closed expect delays	1	29744	29744	29744
Pullman	2003	road construction 9 miles ahead one lane traffic ahead expect delys	1	21963	21963	21963
Pullman	2004	road construction 3 miles ahead left 2 lanes closed expect delays	1	775796	775796	775796
Pullman	2004	road construction 3 miles ahead right lane closed merge left	1	21598	21598	21598
Pullman	2004	road construction 7 miles ahead left 2 lanes closed expect delays	1	28855	28855	28855
Pullman	2004	road construction 7 miles ahead left two lanes closed expect delays	1	9226	9226	9226
Pullman	2004	road construction 9 miles ahead right lane closed merge left	1	25247	25247	25247
Pullman	2004	road construction 9 miles ahead right lanes closed merge left	1	29890	29890	29890
Pullman	2005	road construction 3 miles ahead left two lanes closed expect delays	1	3637	3637	3637
Pullman	2005	road construction 4 miles ahead left two lanes closed expect delays	1	21652	21652	21652
INCIDENT						
Pullman	2003	accident 10 miles ahead expect delays left lane closed 7 miles ahead	1	10834	10834	10834
Pullman	2003	accident 5 miles ahead merge right	1	735	735	735
Pullman	2003	accident 7 miles ahead left lane closed expect delays	1	30839	30839	30839
Pullman	2004	accident 10 miles ahead left 2 lanes closed merge right	1	4585	4585	4585
Pullman	2005	accident 35 miles ahead accident near vega tx. expect delays	1	890	890	890
OTHER						
Pullman	2003	drink drive go to jail	9	229094.7778	636	864329
Pullman	2003	sign under test 123 abc sign under test 123 abc	3	2163.666667	1525	2970
Pullman	2004	caution roads may be icy tune radio to 1610 am	1	84063	84063	84063
Pullman	2004	caution slow moving traffic 42 miles ahead expect delays	1	8973	8973	8973
Pullman	2004	click it or ticket buckle up	8	218725.875	85281	602454
Pullman	2004	drink drive go to jail	2	85006	83741	86271
Pullman	2004	sign under test 123 abc sign under test 123 abc	4	950.75	336	1570
Pullman	2004	txdot test message test message txdot	1	1805	1805	1805
Pullman	2004	water over roadway 9 miles ahead expect delays	1	3374	3374	3374
Pullman	2004	you drink and drive you lose	10	112231.4	75454	172758
Pullman	2005	I40 closed at tucumcari nm 1-800-432-4269	1	3640	3640	3640
Pullman	2004	kidnapped child brown chevy p/u call police kidnapped child houston tx lic tx vs2037	1	28848	28848	28848
Pullman	2005	sign under test 123 abc sign under test 123 abc	1	2042	2042	2042
Pullman	2005	texas road conditions 1-800-452-9292	1	74421	74421	74421

Each simulation run was conducted over a 2000-second period. The first 200 seconds were only used to load vehicles into the network and were not considered in the analysis. Therefore, each simulation replicated a 30-minute incident under a two-lane closure and two DMS scenarios, which are summarized in Table 15. The following MOEs were determined from the simulations:

- average travel time (seconds/vehicle),
- average total delay (seconds/vehicle),
- stops,
- maximum queue (feet), and
- stops in queue.

These MOEs were determined for all freeway links upstream of the lane closure. In addition, system-wide MOEs were also determined.

Table 14. Content, Frequency, and Duration of DMS Messages at Dowell Road.

				Duration (seconds)		
DMS	Year	Message	Frequency	Average	Minimum	Maximum
CONSTRUCTION						
Dowell	2003	I27 south road construction one lane traffic follow detour	1	1795620	1795620	1795620
Dowell	2003	bridge construction 15 miles ahead expect delays	2	23452	23452	23452
Dowell	2003	bridge construction 7 miles ahead lanes closed expect delays	1	1711	1711	1711
Dowell	2003	bridge construction 8 miles ahead	2	344309.5	15721	672898
Dowell	2003	bridge construction 8 miles ahead lanes closed expect delays	1	432551	432551	432551
Dowell	2003	bridge construction 8 miles ahead lanes closed merge right follow detour	1	28848	28848	28848
Dowell	2003	bridge construction I40/washington lanes closed 8 miles ahead merge right	2	91964.5	60888	123041
Dowell	2003	road construction 5 miles ahead left two lanes closed expect delays	1	30428	30428	30428
Dowell	2003	road construction 5 miles ahead right lane closed expect delays	1	28860	28860	28860
Dowell	2003	road construction 7 miles ahead left two lanes closed expect delays	2	651794.5	7848	1295741
Dowell	2003	road construction 8 miles ahead left two lanes closed expect delays	2	572570.5	9002	1136139
Dowell	2003	road construction 8 miles ahead one lane traffic ahead expect delys	1	14566	14566	14566
Dowell	2003	road construction 8 miles ahead right two lanes closed expect delays	1	17007	17007	17007
Dowell	2004	right 2 lanes 5 miles ahead closed western st. exit 67 closed	3	6190.667	4043	7266
Dowell	2004	road construction 4 miles ahead right lane closed merge left	1	36049	36049	36049
Dowell	2004	road construction 5 miles ahead left two lanes closed expect delays	1	25821	25821	25821
Dowell	2004	road construction 7 miles ahead left lane closed expect delays	1	35545	35545	35545
Dowell	2004	road construction 9 miles ahead right lanes closed expect delays	1	7163	7163	7163
Dowell	2005	road construction 3 miles ahead left two lanes closed expect delays	1	22557	22557	22557
INCIDENT						
Dowell	2003	accident 10 miles ahead expect delays all lanes closed 10 miles ahead	1	173	173	173
Dowell	2004	I40 east 7 miles ahead accident expext delays	1	509674	509674	509674
Dowell	2004	accident 10 miles ahead I40/I27 interchange expect delays	1	1120	1120	1120
Dowell	2004	accident 12 miles ahead right 2 lanes closed expect delays	1	7254	7254	7254
Dowell	2004	accident 6 miles ahead right lane closed expect delays	1	1449	1449	1449
OTHER						
Dowell	2003	click it or ticket buckle up	3	197831.7	4753	408343
Dowell	2003	drink drive go to jail	11	158523.3	421	704317
Dowell	2003	sign under test 123 abc sign under test 123 abc	3	2018.333	1497	2971
Dowell	2004	caution roads may be icy tune radio to 1610 am	1	84062	84062	84062
Dowell	2004	click it or ticket buckle up	6	263282.8	86334	805200
Dowell	2004	drink drive go to jail	3	402261.3	83744	950271
Dowell	2004	kidnapped child brown chevy p/u call police kidnapped child houston tx lic tx vs2036	1	28850	28850	28850
Dowell	2004	sign under test 123 abc sign under test 123 abc	4	971.25	345	1668
Dowell	2004	water over roadway 9 miles ahead expect delays	1	3372	3372	3372
Dowell	2004	you drink and drive you lose	3	86351.67	75432	97233
Dowell	2005	I40 closed at tucumcari nm 1-800-432-4269	1	65	65	65
Dowell	2005	sign under test 123 abc sign under test 123 abc	1	2054	2054	2054
Dowell	2005	texas road conditions 1-800-452-9292	2	77441.5	72046	82837

Table 15. Lane Closure and DMS Scenarios.

	No DMS Message	Diversion Message on DMS
One Left Lane Closed	Scenario 1	Scenario 2
Two Left Lanes Closed	Scenario 3	Scenario 4

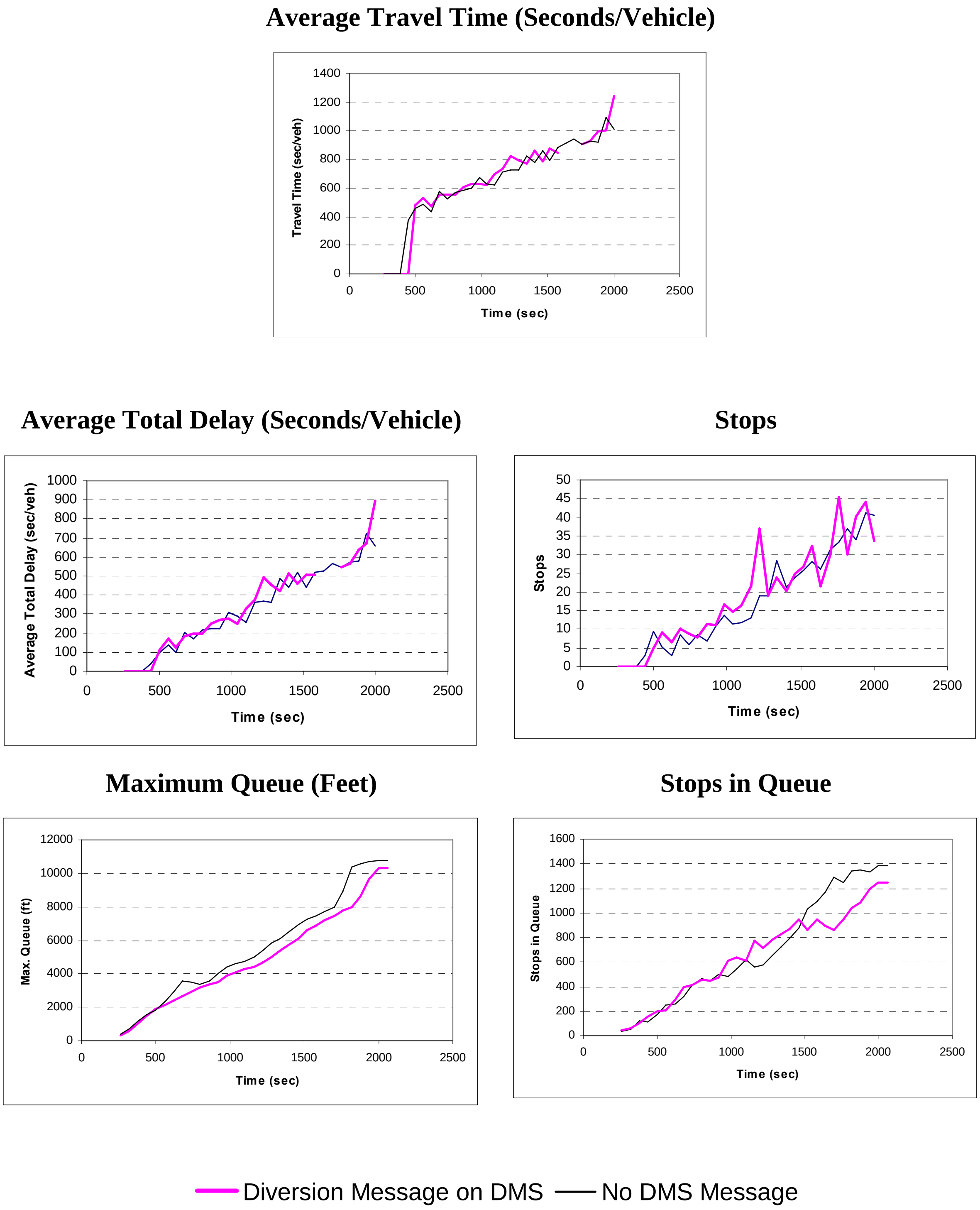
Under scenarios 1 and 2, minimal queuing was observed because of the relatively low volumes. Whenever some queue developed, it was short in length and duration, and did not reach the first exit ramp upstream. Therefore, it never induces any additional traffic diversion to the frontage road. Regardless of the status of the DMS (i.e., diversion message is displayed or not), the MOEs were almost the same when the three lanes were reduced to two (i.e., closure of the left-most lane) under the relatively light traffic conditions. For scenarios 3 and 4, the two left lanes were closed at the same location and under the same traffic conditions as for the single lane closure. Although long queues formed and many drivers diverted to the frontage road, similarly to the previous two scenarios, no significant operational benefit of the DMS was observed. In fact, Figure 17 shows plots of the MOEs.

Network-level MOEs were also determined and summarized in Table 16. The difference between the two DMS scenarios is very small and inconclusive. For some MOEs (e.g., stopped delay), the DMS usage is beneficial, while for other MOEs it is not but with very slight margin. Note that these results correspond to the entire network and incorporate the travel times, stops, and delays at all other freeway sections, frontage roads, arterials, and signals that are outside of the impact area of the simulated incident and the DMS. Since the entire network is much larger than the area affected by the incident, the small differences in network-level MOEs are not that surprising.

Also, the results may be consequences of the many uncertainties and gaps in the input data, such as signal timing plans for each intersection along the frontage roads and some sort of origin-destination estimates for the entire network. Also, it may be a better modeling approach to subdivide the large network into two or three overlapping sub-networks that are easier to handle and provide with sufficient data. Based on such inconclusive results, no reliable determination of the mobility effectiveness of the Amarillo rural DMS corridor seems possible with the data available.

Agency Interviews

Interviews were conducted with TxDOT personnel in the Amarillo District during the second year of DMS operations (2004). The objectives of these interviews were to document the utility of DMS deployment for motorist communication and traffic management. Additionally, problems and successes associated with the deployment and operation of the system were highlights. Comments by Amarillo District personnel are summarized below.



Average Travel Time (Seconds/Vehicle)

Average Total Delay (Seconds/Vehicle)

Stops

Maximum Queue (Feet)

Stops in Queue

Figure 17. Diversion Messages on DMS versus No Diversion Messages on DMS.

Table 16. Network-Level MOE and DMS Scenarios.

Network-Level MOE	DMS	Without DMS
Number of vehicles in the network	4,131	4,062
Total path distance (miles)	40,401.74	39,884.85
Total travel time (hours)	14,74.683	1,462.98
Average speed (mph)	27.397	27.263
Total delay time (hours)	458.051	453.704
Average delay time per vehicle (seconds)	120.902	119.737
Total stopped delay (hours)	182.242	191.544
Average stopped delay per vehicle (seconds)	48.103	50.55

Current DMS Utilization

DMS deployment has changed traffic operations in Amarillo in the sense that TxDOT now has the capability to actively manage the highways. TxDOT has proactively used DMSs to achieve their main goal: keep traffic moving. Being a rural area, Amarillo does not experience congestion issues but instead utilizes DMSs to address other needs. Specific needs that were focused on in Amarillo included heavy trucks (55-60 percent truck traffic on I-40), weather, and coast-to-coast interstate traffic.

A primary aim of DMS deployment was to aid in information dissemination in snowstorm events. Nearby states, especially New Mexico, often shut down their freeways for hours or even days during severe snowstorms and freezes. Amarillo is contacted and asked to shut down their freeways as well to prevent the stranding of motorists. As trucks wait for roads to reopen, freeways in the Amarillo area turn into parking lots. DMSs have been used to warn motorists of these upcoming road closures. Similarly, DMSs are used to warn motorists of icy pavement conditions.

DMSs in Amarillo have also been utilized for advance warning of closures due to construction, high flood waters, crashes, and other incidents. TxDOT may suggest the use of alternate routes in such situations but will not specify a particular route. DMSs have also been used in drinking and driving campaigns and Click It or Ticket campaigns, and have been utilized in AMBER Alerts.

Success of DMS Implementation

The rural DMS application has exceeded the expectations of the TxDOT Amarillo District. Personnel were unsure how DMSs would impact traffic operations in the area; however, there has been a large improvement in mobility. Although a benefit-cost analysis of the implemented ITS has never been conducted, TxDOT believes a benefit-to-cost ratio much greater than one would be achieved.

The largest impact of DMSs in Amarillo has been realized through DMS use in weather emergencies. Although snowstorms have not been as severe since the installations of ITS, New Mexico has closed interstate highways on some occasions. The Amarillo Traffic Management Center posted warning messages on the local DMSs. Large traffic queues did not develop on the Amarillo freeways as in the past. This illustrates an improvement over previous weather emergencies. A previous snowstorm closed freeways in New Mexico, causing Amarillo traffic to be at a standstill for several hours.

The TMC has posted messages warning motorists to take an alternative route due to icy pavement conditions. TMC operators then observed, through closed circuit television (CCTV) cameras, traffic diverting from the freeway in less than a minute. All traffic continued to divert until messages were removed from the signs. Advance warnings of closures, especially due to construction, are frequently posted on the DMS several miles in advance of the site. Traffic engineers expect this significantly improves safety through reduced accidents.

Problems with DMS Deployment

The Amarillo District expected operations of the rural DMS deployment to be fairly low maintenance. Some technical problems occurred during the initial deployment of the system. TxDOT experienced both structural and mechanical issues with the DMS. Since that time, the DMS hardware has been almost flawless.

Future of Amarillo DMSs

The Amarillo District of TxDOT has planned several phases of DMS expansion on area roadways. The Amarillo District has talked about the future use of DMSs as a tool for disseminating tornado warning information. The future use of DMSs in a nuclear or hazardous materials incident is also expected due to high volumes of pass-through truck traffic and the close proximity of a nuclear weapons plant.

Benefit/Cost-Effectiveness

The cost of Phase I of the Amarillo rural corridor, i.e., construction and installation of the previously indicated five DMSs and 10 CCTVs, was approximately $1.5 million. The average annual cost of equipment maintenance and utility expenses for the period December 2002-December 2005 is approximately $42,000 per year. This annual cost does not include TxDOT salaries or labor.

Assuming an average equipment life of 15 years, the cost for equipment maintenance and utilities over this time period is approximately $600,000. Total Phase I Amarillo rural corridor implementation and operation cost is approximately $2.1 million without considering interest or inflation. As discussed previously, no quantitative benefits to mobility could be determined from the simulation modeling. Safety benefits were established along the Amarillo corridor routes from a limited ("fatals only") 2-year only before-after comparative analysis. Applying published (NSC) costs to the accounted crash reduction yielded an average annual safety benefit of approximately $12.6 million.

Based upon the previously discussed evaluation activities, the qualitative results indicate that implementation of the DMS technology as currently configured and operated by the Amarillo District of TxDOT along the I-40 and I-27/ US 87 corridor routes has been highly successful. Surveys conducted after the implementation of DMSs in Amarillo reveal that technology has fulfilled users' (motorists') expectations for real-time advisory information. Similarly, interviews with TxDOT Amarillo District personnel show that the rural DMS applications have created a manageable transportation system. This has allowed TxDOT to work proactively toward improving the safety and mobility needs of Amarillo motorists.

HOUSTON CASE STUDY

Introduction

The second region selected for a case study analysis of the benefits of DMS deployment and usage was the I-45 North Freeway Corridor in Houston. Over an approximately 23-mile segment between an interchange with the Hardy Toll Road on the north and I-10 at downtown on the south, this facility serves between 160,000 and 275,000 vehicles per day (vpd). The freeway consists primarily of four lanes per direction on this segment and has mostly continuous one-way frontage roads adjacent to the freeway main lanes on each side.

Unlike Amarillo, the Houston District has a much more extensive deployment of DMSs and other ITS infrastructure throughout the region. The North Freeway alone has 10 DMSs positioned strategically along this segment and has multiple others located on I-10 and I-610 that can also provide travel information to drivers destined for the North Freeway. The signs themselves are heavily utilized. During calendar year 2004, Transtar operators activated one or more DMSs for nearly 1200 incidents on this freeway segment, an average of more than three per day. The signs were also used numerous times for highway roadwork operations that occurred, for special event traffic management, and for current travel times to downstream locations (on certain DMSs). The messages displayed on the signs provide valuable information to approaching drivers about the location and magnitude of the incidents, presumably leading to a reduced frequency of secondary crashes. However, another important consequence of the displayed messages is to allow motorists to make travel route changes en route if they so choose in order to avoid the incident area. It is these changes in travel behavior and the resulting quantitative impacts on operational measures of performance that were of primary interest in this case study analysis effort.

Preliminary Investigations

Initially, the research team anticipated an analysis approach as outlined in the previous chapter, similar to that followed for the Amarillo case study analysis using a traffic simulation model such as CORSIM or VISSIM. However, as the Amarillo case study evolved, it soon became apparent that the significant data demands required to develop and calibrate a detailed microscopic traffic simulation model for the case study corridor in Houston would quickly overwhelm the funding and time resources allocated to this effort. More importantly, even with a fully constructed and calibrated model, the estimation of potential DMS impacts would be highly dependent upon the assumptions of the analyst and how the model inputs were arbitrarily manipulated. Researchers did attempt to gain insight into how to possibly adjust model inputs through a stated-preference driver survey, whereby study participants were presented a series of hypothetical driving scenarios on the North Freeway along with the availability of information about downstream incidents from DMSs or the radio in their vehicle (see Appendix C for a description of the survey results). The results were similar to other studies of this type in that the resulting diversion percentages implied by the survey results far exceeded what are typically observed in actual driving environments and suggest that route conditions encountered while driving influence responses to DMS information *(38)*. Although some useful insights were obtained (i.e., drivers in Houston appeared to be equally likely to divert whether they receive incident information from a DMS or from their radio), the survey results still meant that the manipulation of traffic simulation inputs would still be primarily dependent on unverifiable assumptions by the analyst in trying to isolate the impacts of DMSs upon traffic operations.

Two key issues were raised as part of these preliminary considerations. The first of these is the choice of appropriate analysis boundaries for estimating DMS impacts. Traditionally, a network-based analysis approach to estimating operational impacts of DMSs is considered appropriate, as motorists could potentially choose to divert to another route far in advance of the actual incident location. This type of approach requires extensive data about all major routes in the network (capacities on each segment, signal timings at each intersection, etc.) and motorist origin-destination information. More importantly, the primary mechanism for evaluating the effects of real-time influences on travel and the resulting MOEs is to manually adjust the motorist origin-destination patterns in some manner to represent how diversion decisions are made. In a large network with many possible locations where diversion decisions can be made and where the combined results of such diversions can themselves further influence diversion decisions (i.e., significant congestion on a frontage road is likely to reduce a driver's decision to divert to the frontage road in response to a DMS message), the value of performing such a network-based analysis is of limited value.

From TxDOT's perspective, the provision of information via DMSs is only intended to offer drivers information that they can use to make changes to their intended route *if so desired*. There is no implied or direct guarantee that any change in a driver's route will in fact improve their trip time. Nevertheless, experiences suggest that the provision of such information is desired by motorists and considered valuable, regardless of how it ultimately affects their overall travel time. In fact, it is surmised that any attempts by TxDOT to manipulate or restrict the provision of information (even if doing so would ultimately lead to overall improvements in network travel costs) would be viewed adversely by the driving public and actually reduce agency credibility. The second issue raised during preliminary investigations relates to the separation of effects of DMS-presented information with real-time information presented via other venues (television, radio, internet, etc.). In a mature ITS environment such as exists in Houston, available real-time information is pushed to travelers through that multitude of venues, of which DMSs are only one mechanism. The stated-preference survey results in Appendix B imply that the source of information in Houston does not currently have a strong influence upon driver diversion potential. Consequently, it is the accessibility or exposure to real-time information that is a primary distinguishing factor. Of the various non-DMS venues of traffic information available to the typical driver, the vehicle radio is believed to be the most prominent within the Houston region. Access to real-time information via the radio is first dependent upon whether or not they are listening to the radio while driving, and secondly upon the frequency and amount of information that is presented on the particular radio station to which they are listening (similar restrictions exist for television and Internet sources for pre-trip travel information). Conversely, all drivers who pass a DMS have the potential to receive the information being displayed at the time they pass the sign. The increased exposure to information and the resulting behavioral changes to that information above and beyond what would otherwise occur are what are of primary interest in estimating the DMS impacts upon traffic operations.

Given these two issues, one must question whether a full network-based evaluation is necessary or even appropriate when attempting to isolate DMS impacts from TxDOT's perspective. It can be argued that diversion from the freeway in response to the information presented on the DMS is a likely consequence of providing information, regardless of whether or not such diversions actually lead to more or less total travel costs in a region. Even if such diversions did increase travel costs in total across the network, “benefits” would be accrued in that drivers have successfully avoided the condition that they desired to avoid as evidenced by their decision to divert. If the typical motorist does not hold TxDOT accountable for the fact that their decision to divert may have increased their total travel costs relative to what might have occurred if they had not diverted, then the analysis approach adopted here might likewise take a similar approach and only consider the implications (benefits) that the provision of DMS information had on reducing the travel “problems” and resulting travel costs on the primary route (i.e., the freeway) of the motorist.

Analysis Approach Used

The approach utilized in this case study was based on a suggestion by the advisory panel early in the project to use observed incident conditions under which queuing on the freeway main lanes occurred as a basis for calibration and estimation of possible DMS effects. Certainly, DMSs are used for much more than just incident management. In fact, incident usage may be only a small portion of the total DMS use in a corridor. Other frequent uses of the DMS include:

- advance and real-time notification of downstream work zone shoulder and lane closures on the freeway (in Houston, most of this type of work occurs at night and on weekends);
- advance and real-time notification of special events (i.e., parking locations, shuttle bus availability, etc.); and
- current travel times to downstream interchanges and destinations along a freeway corridor (travel times much different than typical are believed to induce significant changes in travel patterns, regardless of whether the difference is due to recurrent congestion or because of a downstream incident).

Even though incident management may represent only a portion of the total DMS impacts that are generated in a freeway corridor, it serves as a good case study analysis dataset for guideline demonstration purposes. Incidents occur all along a particular freeway corridor during all hours of the day or night, range in duration from just a few minutes to several hours or more, and reduce roadway capacity by varying amounts depending on how many lanes are blocked.

Consequently, an analysis of these events can serve as a good indicator of the range of impacts that could be generated through the availability of DMS-based information. Furthermore, it may be possible to then extrapolate the results of the analysis under these incident conditions to some of the other DMS uses to gain a broader assessment of the overall magnitude of benefits of having and operating DMSs in a corridor.

If the observed condition was pre-DMS installation, then the likely impacts that introducing one or more DMSs would have on the queue would be the target of the analysis. If the observed condition was post-DMS installation, the likely impacts of not having the DMS present would be estimated in the analysis and compared to the observed conditions. Two challenges existed in accomplishing this approach:

- how to simply and effectively represent freeway queuing conditions and
- how to estimate how DMS presence or absence would likely affect these queuing conditions.

Representation of Freeway Queuing Conditions

A number of simple queuing analysis tools (QuickZone, DELAY, QUEWZ-92, etc.) do exist, but none were considered sufficient for purposes of this analysis. For the most part, these tools are based on the concept of keeping track of traffic entering and leaving a section of freeway over time, accumulating excess input over output as queues that are then dissipated once input drops below output (or the output itself is increased as capacity on the roadway is restored) *(39)*. The problem that exists with this approach in evaluating queuing conditions in urban freeway environments is that the dynamic changes in exit and entrance ramp usage due to the development of queuing upon freeway demand volumes themselves are not captured. Consequently, these types of tools severely overestimate the queues that actually occur at a location, based on historical traffic demand volumes typically available or even actual volumes observed immediately upstream of the queue *(40)*. Unfortunately, this type of modeling challenge is not limited to simple input-output tools; most traffic simulation models do not effectively accommodate dynamic queuing and driver en-route diversion decisions very well either.

Given these limitations, a decision was made to try and use a macroscopic traffic model that represents freeway operations as fluid flow through a section of permeable pipe. This model was successfully used to represent traffic conditions at freeway work zone lane closures in San Antonio. Traffic is envisioned as entering an upstream end of a roadway segment, traveling through the segment, and exiting the other end, just as a fluid flows through a section of pipe. Then, to represent a process where a reduction in roadway capacity due to a work zone generates a stimulus for diversion, the authors have developed a permeable pipe analogy to the traditional pipe flow described above. Figure 18 illustrates the characteristics of this analogy. Initially, flow conditions within the pipe are such that a normal "pressure" of the fluid (p_F) exists within the pipe equal to that acting upon the pipe outside (p_E).

As is the case for traditional compressible fluids operating in a pipe, the "pressure" in the traffic stream is related to the speed of the traffic stream. Because the pressures inside and outside of the roadway segments are equal (i.e., traffic is operating in a state of equilibrium), no energy gradient or seepage flow (υ) exists across the permeable walls of the pipe, and the only direction of flow is longitudinally. Furthermore, the flow rates in and out of the ends of the pipe are equal.

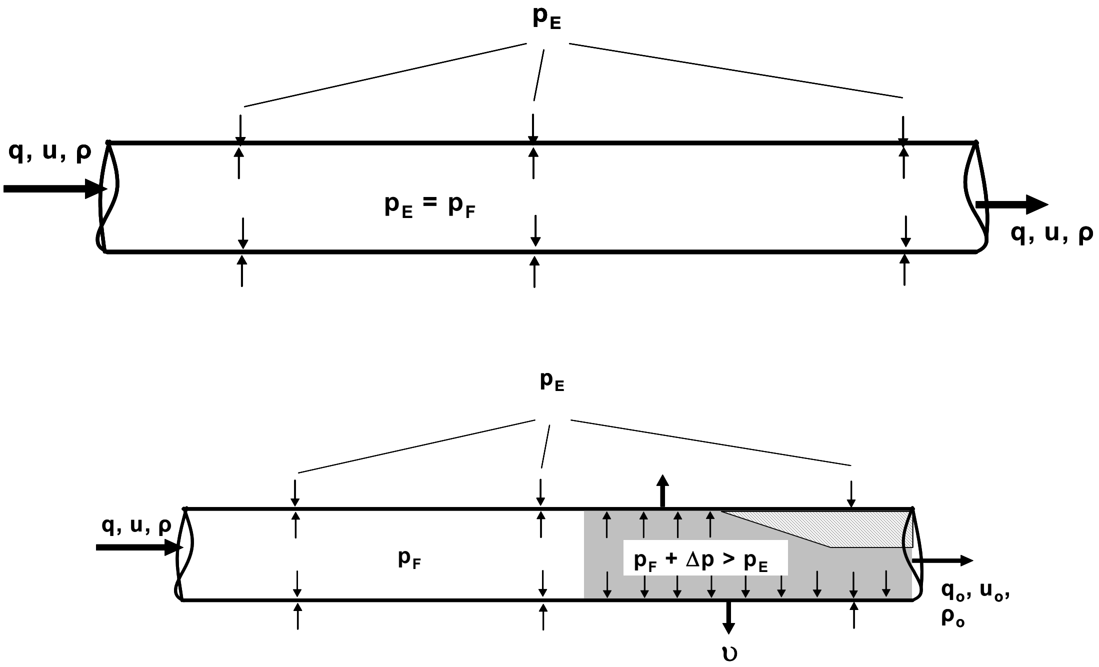


Figure 18. The Permeable Pipe Analogy to Diversion and Traffic Queuing.

This corresponds to normal, stabilized traffic conditions, with typical traffic demands approaching from the upstream end of the roadway segment as well as entering and exiting the roadway at various locations along the roadway segment.

When a temporary bottleneck is placed in the pipe, a change in fluid state begins to propagate upstream from the bottleneck. These conditions are characterized by a lower fluid flow rate out the end of the pipe (q_o), higher fluid density (ρ_o), lower fluid speed (u_o), and most importantly higher fluid pressure ($p_F + \Delta p$) than exist at the upstream end of the pipe. Note that these conditions are identical to the conditions that describe traffic flow, density, and speed in a traffic queue propagating upstream from the bottleneck as well. This increased pressure within the short region of pipe where flow conditions are changed generates an energy differential across the walls that forces flow out through the walls of the pipe. Mathematically, the analogy is based on Darcy's law in soil mechanics, which states that the velocity of flow through a permeable medium is directly related to the energy gradient i that exists across the medium and the coefficient of permeability K of that medium *(41)*:

$$Q = \upsilon A = K\ i\ A \qquad (1)$$

where:

Q = rate of flow through the permeable medium
υ = velocity of fluid flow through the medium
A = area through which flow is occurring
K = coefficient of permeability
i = energy gradient across the permeable medium

Using this analogy, vehicle queuing on the roadway upstream of the work zone corresponds to the region of high-density (and thus high-pressure) fluid upstream of the bottleneck in the permeable pipe. Diversion of the normal traffic volumes from the freeway is then analogous to the flow from inside the pipe permeating through the wall of the pipe within the region of higher pressure.

An extension of shockwave theory is first used in this analogy to estimate the propagation of queuing upstream of a freeway bottleneck and the change in flow conditions within that queue. It is convenient to think in terms of a series of very short time periods (Δt) and to examine the flow conditions and queue growth process on the roadway after each of these periods. The process begins with the flow rate past the lane closure bottleneck (i.e., the reduced work zone capacity), assumed to be constant. At some time period after the bottleneck has been introduced, a shock wave separating the low- and high-density traffic stream conditions has moved upstream some small distance (Δx_{1}) as shown in Figure 19.

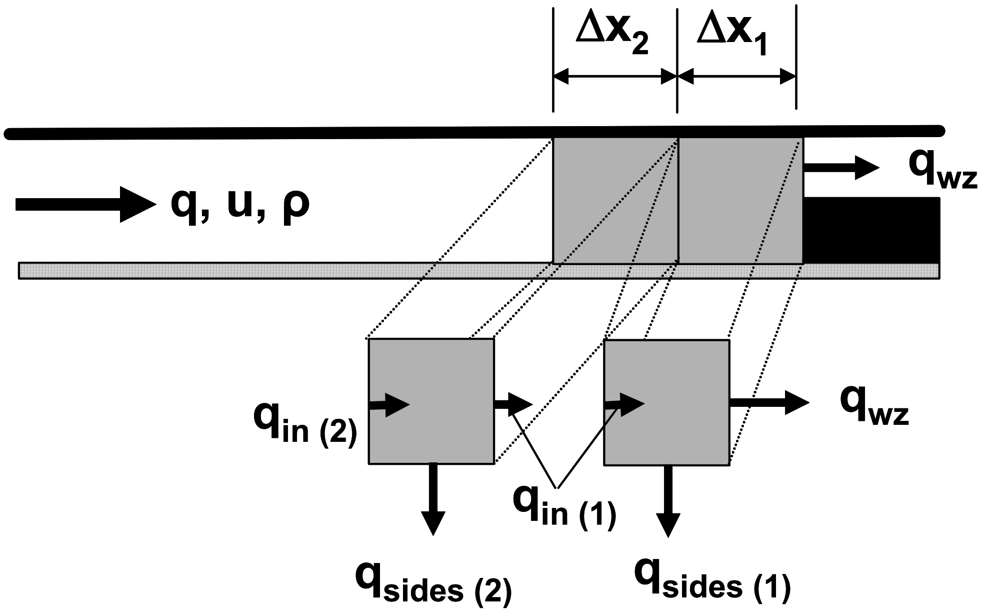


Figure 19. Traffic Conditions a Short Time after Queuing Begins.

This distance is that traveled by the shock wave during that time period:

$$\Delta x_1 = \overline{W}_1 \, \Delta t$$

Lighthill and Whitham's model of shockwave formulation is used as the basis for calculation of the average shockwave speed *(42)*:

$$\overline{W}_1 = \frac{\overline{q}_1 - q}{\overline{\rho}_1 - \rho} \qquad (2)$$

where:

$\overline{W}_1$ = average speed of the shockwave moving a distance Δx_1 during the time interval Δt

$\overline{q}_1$, $\overline{\rho}_1$ = average flow rate and vehicle density within the interval Δx_1 of the freeway queue

q, ▯ = normal flow rate and vehicle density of the traffic stream approaching the queue (i.e., historical traffic demands normally on the freeway at that location)

Unlike traditional applications of shockwave theory, averages are designated in the above equations because the flow rate at the upstream end of the distance (Δx_1) is slightly greater than the flow rate at the downstream end due to diversion flow seeping away from the freeway over that distance. Designating these upstream and downstream flow rates as $q_{in(1)}$ and q_{wz}, respectively (the downstream flow rate of Δx_1 is the capacity of the work zone), Figure 19 illustrates that:

$$q_{in(1)} = q_{wz} + q_{side(1)} \tag{3}$$

Then, during the next time period:

$$q_{in(2)} = q_{in(1)} + q_{side(2)}$$

and so on. Ultimately, this is a recursive relationship that can be written as a function of the capacity of the work zone and the sum of the flow "permeating" out the sides of the pipe through each of the Δx_i segments:

$$q_{in(i)} = q_{wz} + \sum_i q_{side(i)} \tag{4}$$

In order to estimate the amount of flow that permeates out the sides of each segment, the traffic stream speed in that segment must be estimated for use in the energy analogy of traffic flow (described in the next section). The average speed and vehicle density of the traffic stream within each of these small distances Δx can be computed using an assumed relationship between speed and density. For simplicity purposes, Greenshields' well-known linear speed-density model is solved for the average speed within the queue $\bar{u}_l$ by means of the quadratic equation (43):

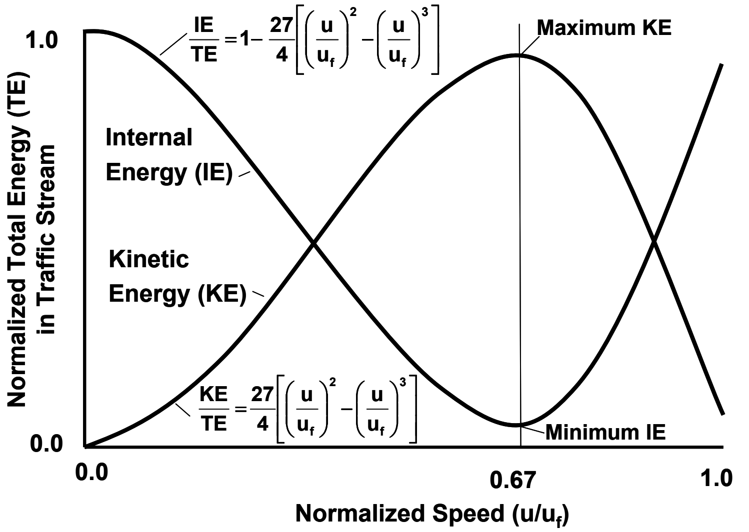
$$\bar{u}_l = \frac{u_f k_j - \sqrt{(u_f k_j)^2 - 4 u_f k_j \bar{q}_l}}{2 k_j} \qquad (5)$$

where:

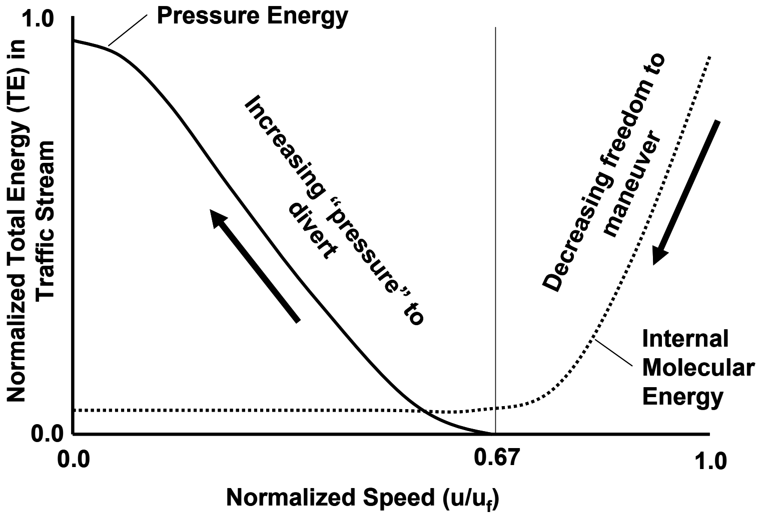
u_f = free-flow speed upstream of the queue
k_j = jam density upstream of the queue

The energy analogy of traffic flow, successfully utilized by Drew et al. *(44)* to describe freeway level of service and by Dudek *(45)* for describing freeway operational control requirements was used to estimate the energy gradient portion of the analogy.

Utilizing speed as the primary determinant, the total energy of the traffic stream on the freeway is divided into its kinetic and internal energy components (KE and IE, respectively). Kinetic energy maximizes at the point (termed the critical speed) where the internal energy is minimized. At traffic speeds above or below that critical speed, some amount of kinetic energy is converted into internal energy. Figure 20(a) illustrates the original representation of the theorized relationships between kinetic and internal energy. To describe the stimulus for diversion at temporary work zone bottlenecks, the internal energy component is further divided into a traffic stream pressure (Δp) and a "molecular internal energy" component that is related to the freedom of individual vehicles to move about within the freeway section. At traffic speeds above the critical speed, all of the internal energy is visualized as molecular internal energy (drivers have considerable latitude in choosing their speed and lane position). However, at traffic speeds below the critical speed, the molecular internal energy is minimized, representing a restriction on vehicles to move freely about on the roadway, and the increase in internal energy increases the traffic stream pressure between that roadway and the rest of the corridor. Figure 20(b) graphically illustrates the separation of the internal energy component.



(a) The Original Traffic Stream Energy Analogy (XX, *XX*)



(b) Decomposition of the Internal Energy Analogy

Figure 20. The Energy Analogy of Macroscopic Traffic Flow.

Mathematically, the increase in normalized traffic stream pressure within a section of queue is formulated as follows:

$$\frac{\Delta\bar{p}_i}{TE} = \frac{1}{(1+\beta)} - \frac{27}{4(1+\beta)}\left[\left(\frac{\bar{u}_i}{u_f}\right)^2 - \left(\frac{\bar{u}_i}{u_f}\right)^3\right] \text{ if } \bar{u}_i < \frac{2}{3}u_f; \qquad \frac{\Delta\bar{p}_i}{TE} = 0 \quad \text{otherwise} \qquad (6)$$

and

$$\beta = \frac{\sigma_{\min}}{\frac{4}{27}\alpha\, k_j\, u_f^{2}}$$

where:

$\Delta\bar{p}_i$ = average traffic stream pressure within a specified section i of the queue

TE = total energy of the traffic stream

β = parameter related to the portion of the traffic stream that is not likely to divert, regardless of the increase in traffic stream pressure

Presenting the change in traffic stream pressure in this manner emphasizes that the maximum increase in pressure energy is less than the total energy of the traffic stream and that there is no pressure contribution in the traffic stream to cause diversion when speeds are greater than the speed at critical energy. Normalizing the pressure function as shown in Equation 5 eliminates the need to compute the total energy of the traffic stream for a given freeway segment in order to describe the relationship between diversion pressure and speed in the traffic stream. Ultimately, the diversion flow rate $q_{Side(1)}$ from Figure 19 is determined using the average normalized increase in pressure over the interval (designated with the bar over the pressure variable) as the energy gradient:

$$q_{side\,(1)} = KiA \equiv K' \frac{\Delta\bar{p}_1}{TE}\Delta x_1$$

where:

K' = permeability factor to account for the diversion potential of the roadway corridor

$\Delta\bar{p}_1$ = average traffic stream pressure differential between the roadway and the rest of the corridor within Δx_1

The average flow rate q_1 within Δx_1 depends on the average speed of the traffic stream u_1 (from Equations 5 and 6), whereas u_1 depends on q_1 (from Equations 2 through 4). Consequently, this system of equations is indeterminate. An approximation technique can be used to help solve these equations. The simplest technique is to limit the size of the interval to a very small distance with a very small time increment Δt and use the flow rate and average speed out of the downstream end of the interval as the average value over the interval.

The contention made for this algorithm is that a single corridor permeability factor K can be used to represent the combined effects of natural diversion along a roadway segment in an urban area. This factor is hypothesized to reflect the ease with which drivers can find and will select other routes to their destination should they encounter unexpected congestion resulting from lane blockages on their intended route. Consequently, more alternative routes available in the corridor, good continuity of those routes, more frequent ramps available where diversion can occur, and better operating conditions drivers expect on the other routes in the corridor all likely increase the value of the permeability calibration coefficient.

Additional details concerning model development, the estimation of vehicle delays incurred within the queue with this analogy, and calibration of the corridor permeability coefficient can be found elsewhere (*46*, *47*).

Accounting for DMS Influences

The second major challenge in the case study analysis was in how to best account for the effects that DMSs have upon either the observed (if already installed) or expected (if not yet installed) traffic conditions being evaluated. As stated previously, the interrelationship between DMS influences and the actual freeway conditions observed by drivers is known to exist, but likely highly dependent upon localized characteristics of the roadway network. The fact that freeway queues have been observed to stabilize in locations where DMSs and other real-time information sources have not existed illustrates the influence of the queue itself upon travel patterns. Thus, the effect of a DMS or series of DMSs should be viewed as having an incremental effect on travel patterns in combination with the freeway queue itself and the other information sources noted previously as well.

It is useful to think about DMS influences in terms of their potential exposure to drivers who will ultimately have a use for such information. Given a typical pattern of freeway usage from a given entrance to a given exit ramp, the amount of traffic passing a given freeway DMS that will be destined for an exit ramp beyond the location of the incident or its subsequent queue will decrease as the distance between the DMS and the incident increases (as suggested in Figure 21). Where multiple DMSs are located on a freeway with frequent entrance and exit ramps upstream of a particular incident location, an incident message at the DMS closer to the incident would be of potential interest to more freeway users passing the sign than one farther away, since more of the drivers at that point are destined beyond the incident location. Conversely, for a DMS located very close to an incident where traffic queuing has developed and extends upstream beyond the sign, the queue itself will have a major influence upon diversion regardless of whether or not a message is displayed. In Figure 21, once drivers on the freeway reach exit 3, their behavior is likely to be more influenced by the queuing conditions on the freeway and frontage road than on the fact that DMS information was presented to them upstream.

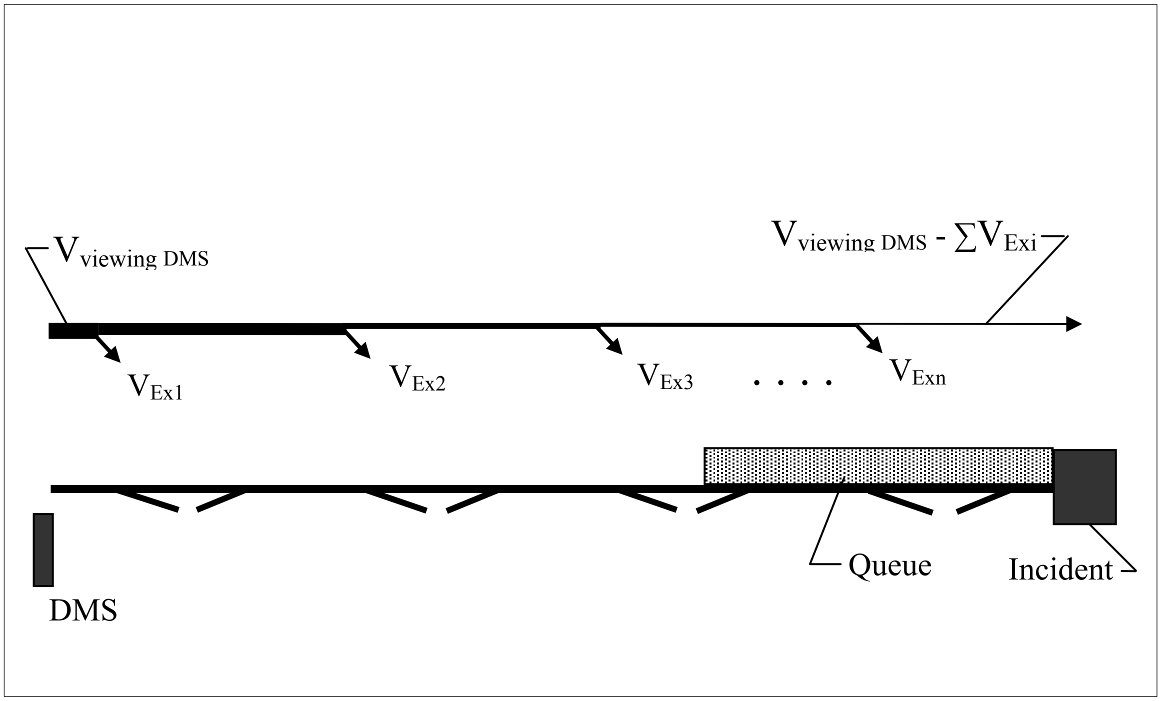


Figure 21. Effect of DMS Distance Upstream on Diversion Potential to a Downstream Incident.

Considering both influences together, changes in freeway volumes (relative to normal conditions expected) immediately upstream of the extent of the queue for an incident would be the maximum amount of diversion that could theoretically be attributed to the influence of the DMS. While it could be argued that this approach would ignore the effects that other information sources (radio, television, Internet, etc.) may have on diversion, the results of the stated-preference survey (Appendix B) suggest that the relative influence of those other sources would be very minor (e.g., only about one-third of the survey respondents indicated even listening to the radio on a regular basis for traffic broadcasts during their trips).

Case Study Methodology

To test the potential usefulness of the above-described macroscopic analysis approach, traffic incidents recorded by Transtar operators during the 2004 calendar year were selected for use. To begin, researchers divided the freeway segment into five subsections as depicted in Figure 22:

- Hardy Toll Road North to Cypresswood Drive,
- Cypresswood Drive to Beltway 8,
- Beltway 8 to North Shepard Drive,
- North Shepard Drive to I-610, and
- I-610 to I-10.

Within each subsection, researchers determined the frequency of incidents for which DMSs were used, stratified by time of day, duration of incident, and effect of capacity (number of lanes closed). Altogether, about 1200 such incidents occurred which were stratified by this procedure. An example of the stratification is shown in Table 17 for the northbound subsection from I-10 to I-610. Appendix C includes tables for other subsections.

Desirably, it would have been most preferable to have collected actual approach volumes, reduced capacity flow rates, and queue lengths resulting from all, or at least a sample, of these incidents during the year. Such a sample would have allowed for the calibration of the permeability coefficient of the analysis tool to these conditions and also to estimate the potential impact of DMS use upon the approach volumes to the upstream end of the queue (comparing the observed volumes during the incident to a sample of historical volumes at the same location on

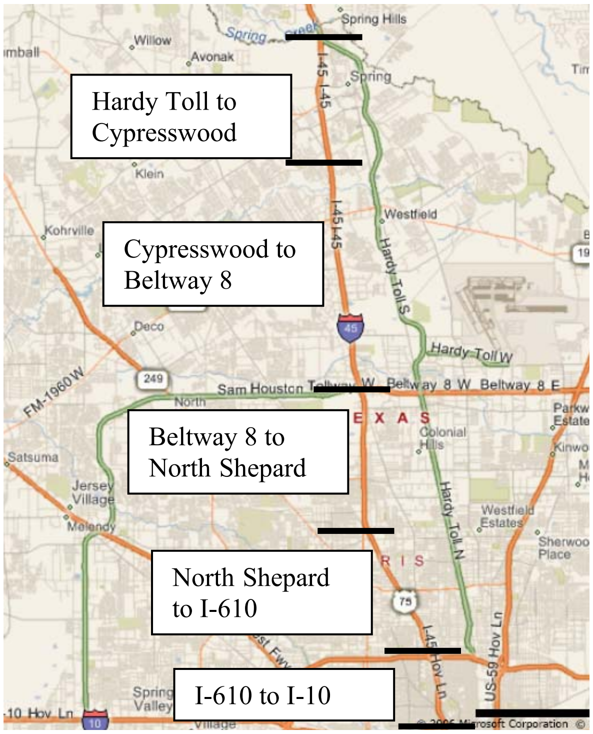


Figure 22. I-45 North Freeway Subsections Used for Case Study Analysis.

days when incidents were not present). Unfortunately, these data were not available for any of the incidents in the segment for the period of interest. Rather than abandon the case study effort, though, researchers decided to use AADT data from the 2004 TxDOT Roadway Inventory File for the freeway segment, together with hourly and directional distributions from ATR count stations on similar freeway sections, as an indication of the "normal" hourly traffic demands on the various subsections. Researchers then conducted a hypothetical analysis of the changes in queue length and vehicle delay that would have occurred between an estimate of queues that would be estimated to exist if "normal" volumes existed immediately upstream of the incident (indicative of a no-DMS condition) and under a certain proportional reduction in the approach volume immediately upstream of a queue (indicative of a DMS-influenced condition). To the extent that the assumptions regarding "normal" traffic volumes within each time period and freeway sub-section as well as the DMS diversion influences are reasonable, the reported results can be used as a general indication of estimated DMS impacts in the freeway segment during incident conditions.

Table 17. 2004 Incidents at I-45 Northbound I-10 to I-610.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage	3	1	5	2	
	1 of 4	6	2	3		
	2 of 4	8	2	4		
	3 of 4	2	1			
	4 of 4					
6A – 9A	Shoulder Blockage	1	3	1		
	1 of 4	8	7			
	2 of 4	2	3	3		
	3 of 4		1	1		
	4 of 4		1			
9A – 3P	Shoulder Blockage	6	4	3	1	
	1 of 4	8	6	5		
	2 of 4	1	5	3	3	
	3 of 4		1			
	4 of 4					
3P – 7P	Shoulder Blockage	4	1	5	2	
	1 of 4	15	7	4	2	
	2 of 4	3	5	2		2
	3 of 4			1		
	4 of 4					
7P – 12A	Shoulder Blockage	4	1			2
	1 of 4	5	1			
	2 of 4	4	3	3		1
	3 of 4	3				
	4 of 4					

Table 18 presents the average hourly demand volumes assumed by direction, time period, and subsection along the freeway segment. For purposes of the case study analysis, capacity values of 2200 vehicles per hour per lane were assumed. Researchers then relied on the FHWA *Traffic Incident Management Handbook* estimates of how various shoulder and lane blockages affect available roadway capacity (*48*). The following capacity reduction values were used:

- shoulder blockage—8 percent reduction in capacity,
- 1 of 4 lanes blocked—42 percent reduction in capacity,
- 2 of 4 lanes blocked—75 percent reduction in capacity, and
- 3 of 4 lanes blocked—87 percent reduction in capacity.

Table 18. Non-incident Average Hourly Volumes Assumed for Subsections (vph).

	12A – 6A	**6A – 9A**	**9A – 3P**	**3P – 7P**	**7P – 12A**
Southbound:					
Hardy Toll Road to Cypresswood	1536	2547	4608	5780	2991
Cypresswood to Beltway 8	1794	3636	5383	5525	3494
Beltway 8 to North Shepard Drive	2181	4420	6544	6716	4248
North Shepard Drive to I-610	2572	5213	7718	7921	5010
I-610 to I-10	2572	5213	7718	7921	5010
Northbound:					
I-10 to I-610	2573	4265	7718	8800	6210
I-610 to North Shepard Drive	2573	4265	7718	8800	6210
North Shepard Drive to Beltway 8	2181	3617	6544	8209	4248
Beltway 8 to Cypresswood	1794	2975	5383	6753	3494
Cypresswood to Hardy Toll Road	1536	2547	4608	5780	2991

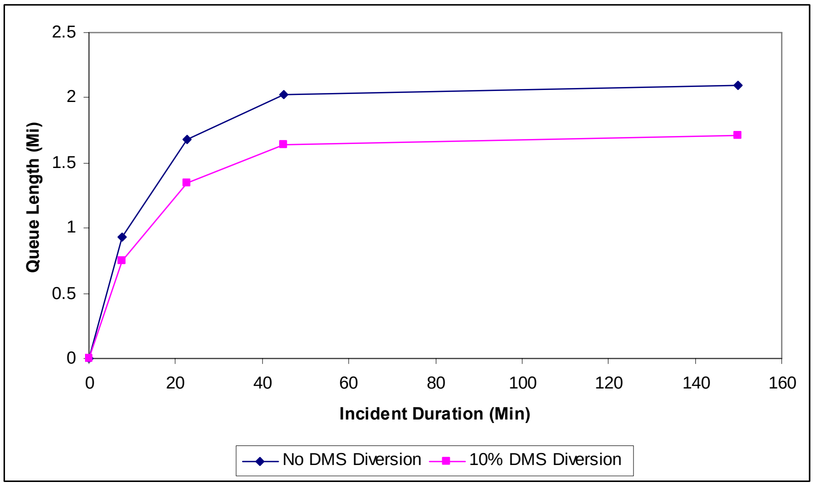
To simplify the analysis process, conditions where the normal demands assumed to exist at the time of the incident were still less than the reduced capacity past the incident were not evaluated. Although it is possible that some diversion may have occurred, the incremental change upon travel times and, thus, delays would be minimal compared to those achieved when demands exceeded capacity and queues formed. Furthermore, the potential also exists that some drivers may actually travel slightly slower when informed of a downstream incident in anticipation of possibly encountering slow or stopped traffic due to that incident, thus offsetting any small increase in travel times that other drivers may experience. Without quality information on these (likely) small changes in travel conditions past the incident when queues have not formed, researchers deemed it more conservative to simply ignore them in this case study analysis.

Since actual queue length, approach volume, and reduced capacity data were not available from which to calibrate the model to account for normal diversion that occurs due to the development of congestion, researchers tested both an upper and lower value of the permeability coefficient as measured on I-410 in San Antonio during temporary work zone lane closures *(47)*. In that study, the corridor permeability coefficient ranged between 1650 vehicles/mile^2/hour for a freeway segment without continuous frontage roads and approximately 4000 vehicles/mile^2/hour for a highly permeable corridor segment with continuous frontage roads and good parallel arterial streets nearby.

Results

The permeable pipe model of macroscopic traffic flow was developed into a simple BASIC program to facilitate repeated calculations of the various incident conditions (location, time period, duration, and number of lanes closed) for the corridor. The algorithm yielded estimates of queue lengths and additional vehicle delay under the different assumed approach volumes (volumes normally expected at the time of the incident, 5 percent lower volumes due to DMS diversion, and 10 percent lower volumes due to DMS diversion) and corridor permeability coefficients (1650 and 4000 vehicles/mile^2/hour). Differences between the estimated additional vehicle delays for the different assumed volume levels thus represented the incremental estimated benefits due to DMSs and resulting diversion upstream of the traffic queue. These vehicle-delay differences were then multiplied by an assumed road-user cost value of $13.50/vehicle-hour, extracted from a recent FHWA publication on life-cycle cost analysis and updated to 2004 dollars *(49)*. The analysis does not include any differences in fuel consumption or other vehicle operating costs. However, given the fact that motorist delay typically far exceeds these other types of road-user costs incurred under queued roadway conditions, this limitation was not believed to significantly degrade the quality of results obtained.

Because of how the algorithm is formulated, queues upstream of an incident are estimated to quickly stabilize at some length and remain at that length as long as the demand volume and reduced capacity are assumed to exist. The actual stabilization length will then differ slightly between the normal and assumed DMS diversion conditions because the demand volume approaching the queue is assumed to be slightly different. This is depicted graphically in Figure 23, which shows the estimated queue length for a no-DMS diversion (i.e., normal assumed volumes) and a 10 percent DMS diversion condition for two-lane-blocking incidents of various durations occurring southbound on I-45 from midnight-6 am. In this graph, the corridor permeability coefficient (K') was assumed to be 1650 vehicles/mile^2/hour. The effect of the queues on total cumulative vehicle delay for the same conditions is also depicted in Figure 23.



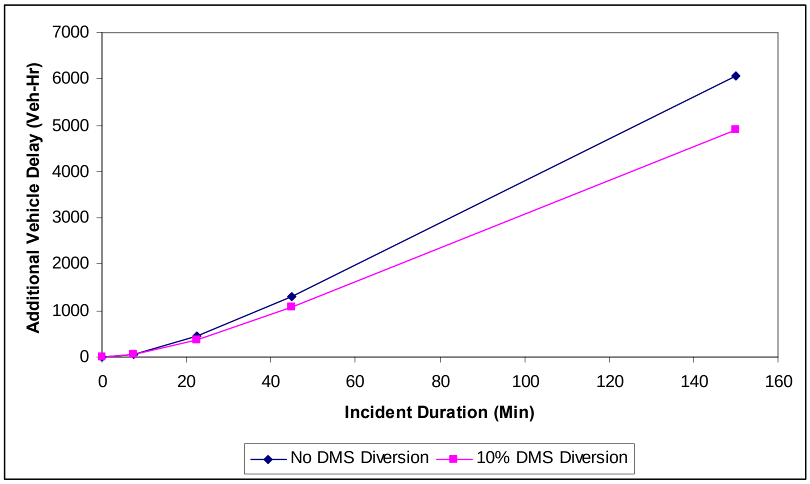


Figure 23. Estimated Queue Lengths and Vehicle Delays: Two Lanes Blocked, North Shepard—I-610 Southbound, 12 am-6 am, K' = 1650 vehicles/mile^2/hour.

The difference between the two lines in the figure represents the calculated reduction in delay due to DMS diversion for these particular incident conditions.

As might be expected, the estimates of queue length and delay with this algorithm are highly dependent upon the corridor permeability coefficient used in the analysis. Figure 24 shows the estimated queue lengths and total cumulative vehicle delays computed for a no-DMS diversion condition for the same incident scenarios assuming corridor permeability coefficients of either 1650 or 4000 vehicles/mile^2/hour. Comparing these last two figures together, one sees that the range of permeability coefficients assumed for this analysis has a bigger influence on both queue lengths and delays than does the estimated effect of a 10 percent DMS diversion effect. Such a

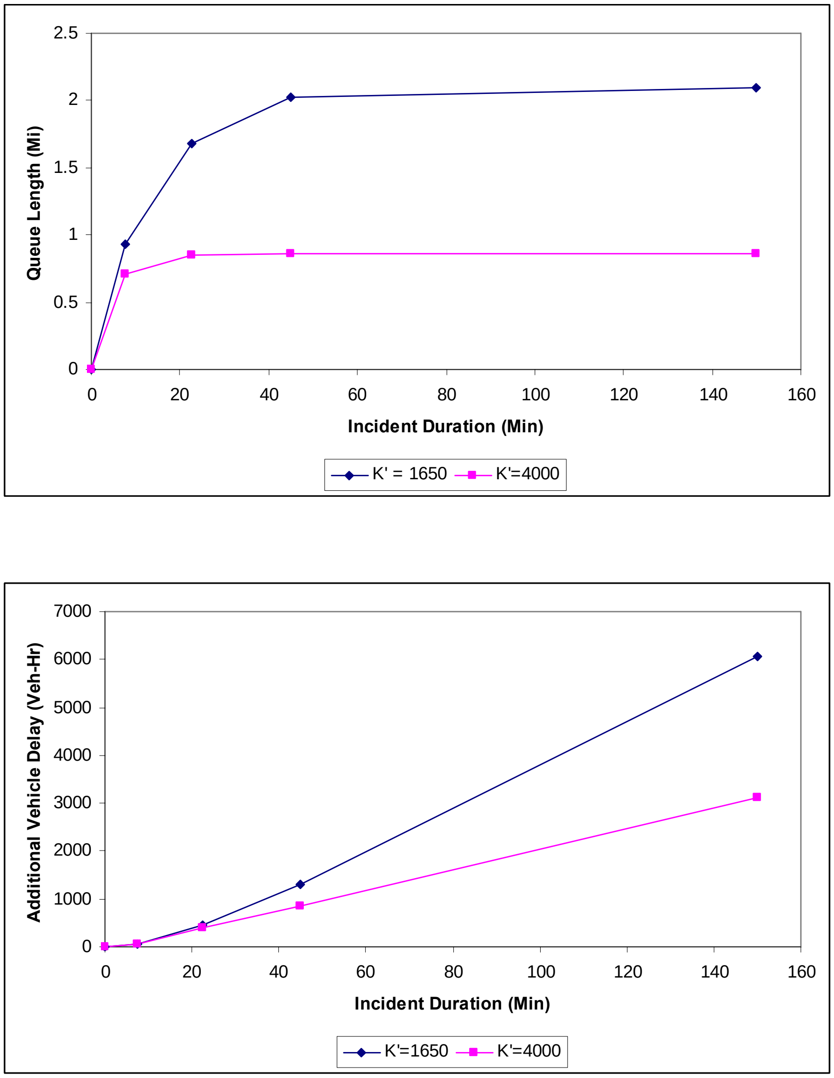


Figure 24. Effect of Corridor Permeability Coefficient upon Estimated Queue Lengths and Vehicle Delays: Two Lanes Blocked, North Shepard—I-610 Southbound, 12 am-6 am, 10 Percent DMS Diversion.

result indicates a strong need to develop calibrated coefficients based on actual data from the corridor rather than rely on assumed values from other corridors as was done in this case study.

For each incident scenario of interest in the corridor, researchers computed queue lengths and additional vehicle delays under the different assumed DMS diversion percentages (5 percent and 10 percent) and assumed corridor permeability coefficients (1650 and 4000 vehicles/mile^2/hour). Only those conditions where assumed traffic demands exceeded the reduced capacity past the incident were analyzed. In addition, the algorithm could not be applied to incidents occurring during the PM peak period between I-10 and North Shepard since this section appears to regularly queue and exceed capacity under normal conditions and so operates outside of the range of analysis capabilities of the model. Even with these conditions removed, however, researchers analyzed just over 1100 applications of the algorithm for the corridor. For each individual incident scenario, results from the 5 percent and 10 percent DMS diversion computations were then subtracted from the no-DMS diversion computations to estimate the incremental difference that this level of diversion would have had upon additional vehicle delays computed for that incident scenario. In Tables 19 through 22, researchers have summarized the estimated reduction in delay computed in each direction of travel on I-45 during incidents assuming either a 5 or a 10 percent additional diversion away from the freeway due to the presence of DMSs. In each cell of the table, the lower range represents the estimates under a highly permeable corridor (K'=4000 vehicles/mile^2/hour), and the upper range represents the estimates under a less permeable corridor (K'=1650 vehicles/mile^2/hour). As might be expected, total estimated delay reductions for a 10 percent DMS diversion assumption are almost twice those for an assumed 5 percent DMS diversion. Because the influence of queuing itself on diversion that naturally occurs has been taken into consideration in the analyses, the estimates shown in the tables are believed to be more realistic than those that would have been estimated if this natural diversion process had not been taken into consideration.

In Table 23, researchers have summed the total delay reductions estimated under the various diversion and corridor permeability assumptions made and multiplied them by a unit value of travel time of $13.50/vehicle-hour in order to calculate an estimate of the yearly annual benefits in mobility improvements gained by the use of DMSs during incidents in the I-45 corridor. Based on the analyses conducted, researchers have estimated these benefits at between $400,000 and $1.2 million annually.

It must be remembered that these values represent a demonstration of a possible analytical approach to estimating DMS benefits in a dense urban freeway corridor with frequent ramps, a multitude of potential alternative routes, etc. Had actual data on traffic volumes and queue lengths upstream been collected for a sample of incidents, it would have been possible to actually calibrate the algorithm for both the corridor permeability coefficient and for the actual amount of

Table 19. Estimated Yearly Delay Reductions for 5 Percent DMS Diversion during Incidents on I-45 Northbound (Vehicle-Hours).

Segment	12A-6A	6A-9A	9A-3P	3P-7P	7P-12A	Total
I-10 to I-610	196-287	590-701	2,420-3,457	N/A	927-1,584	**4,133-6,028**
I-610 to North Shepard	214-310	1,156-1,248	4,432-6,287	N/A	785-1,420	**6,587-9,265**
North Shepard to Beltway 8	39-55	168-294	362-403	635-1,137	196-344	**1,399-2,234**
Beltway 8 to Cypresswood	55-82	66-97	335-414	373-524	92-114	**921-1,231**
Cypresswood to Hardy Toll Road	0	10-14	28-33	45-64	49-54	**132-165**
Total	**504-734**	**1,990-2,354**	**7,577-10,954**	**1,053-1,725***	**2,049-3,516**	**13,172-18,923**

N/A = estimates not available

* Represents only those locations where normal demands < normal roadway capacity

Table 20. Estimated Yearly Delay Reductions for 10 Percent DMS Diversion during Incidents on I-45 North Freeway Northbound (Vehicle-Hours).

Segment	12A-6A	6A-9A	9A-3P	3P-7P	7P-12A	Total
I-10 to I-610	392-566	1,165-1,389	4,955-7,069	N/A	1,856-3,168	**8,369-12,190**
I-610 to North Shepard	422-611	2,290-3,390	8,728-12,758	N/A	2,121-3,355	**13,560-20,115**
North Shepard to Beltway 8	76-109	330-579	713-1,085	1,399-2,417	386-680	**2,903-4,870**
Beltway 8 to Cypresswood	107-162	128-190	665-823	744-1,042	181-225	**1,826-2,442**
Cypresswood to Hardy Toll Road	0	20-28	56-65	87-127	107-98	**269-318**
Total	**997-1,448**	**3,933-5,738**	**15,117-21,800**	**2,230-3,586**	**4,651-7,526**	**26,972-39,935**

Table 21. Estimated Yearly Delay Reductions for 5 Percent DMS Diversion during Incidents on I-45 Southbound (Vehicle-Hours).

Segment	12A-6A	6A-9A	9A-3P	3P-7P	7P-12A	Total
Hardy Toll Road to Cypresswood	0	350-417	0	36-38	0	**386-455**
Cypresswood to Beltway 8	0	733-834	2,297-3,596	420-516	50-54	**3,499-4,999**
Beltway 8 to North Shepard	2	88-122	469-743	1,098-2,082	99-134	**1,756-3,083**
North Shepard to I-610	167-261	625-948	2,701-3,945	2,344-3,556	1,058-1,336	**6,894-10,046**
I-610 to I-10	119-200	446-451	2,443-3,228	806-1,034	599-766	**4,414-5,680**
Total	**288-463**	**2,242-2,772**	**7,910-11,512**	**4,704-7,226**	**1,806-2,290**	**16,949-24,263**

N/A = estimates not available

* Represents only those locations where normal demands < normal roadway capacity

Table 22. Estimated Yearly Delay Reductions for 10 Percent DMS Diversion during Incidents on I-45 North Freeway Southbound (Vehicle-Hours).

Segment	12A-6A	6A-9A	9A-3P	3P-7P	7P-12A	Total
Hardy Toll Road to Cypresswood	0	697-830	0	71-76	0	**768-906**
Cypresswood to Beltway 8	0	1,467-1,670	4,123-6,418	758-908	117-133	**6,465-9,129**
Beltway 8 to North Shepard	4-5	199-272	941-1,490	2,205-3,663	197-268	**3,544-5,697**
North Shepard to I-610	323-468	1,239-1,885	5,524-8,053	4,893-7,492	2,093-2,654	**14,072-20,553**
I-610 to I-10	234-394	585-755	4,954-6,518	1,456-1,851	1,191-1,528	**8,420-11,046**
Total	**561-867**	**4,187-5,412**	**15,542-22,479**	**9,383-13,390**	**3,598-4,583**	**30,269-47,341**

Table 23. Estimated Annual Delay Reduction and Road User Benefits of DMS Use during Incidents on I-45.

	5% DMS Diversion		10% DMS Diversion	
	Delay Reduction (Vehicle-Hours)	**Road User Benefits**	**Delay Reduction (Vehicle-Hours)**	**Road User Benefits**
I-45 Northbound	13,172-18,923	$177,872-$255,461	26,972-39,935	$364,122-$599,133
I-45 Southbound	16,949-24,263	$228,812-$372,551	30,269-47,341	$408,632-$639,104
TOTAL	**30,121-43,186**	**$406,634-$583,011**	**57,241-87,276**	**$772,753-$1,178,226**

DMS diversion that was likely experienced (i.e., by comparing non-incident normal volumes on the freeway just upstream of the queues at that time of the day to the volumes actually observed approaching the queue during the incident).

It must also be remembered that the analysis was limited in scope to just incident uses of the DMSs. As noted previously, the DMSs in the corridor are actually used much more than for incident management. Consequently, the values shown in Table 23 are likely only a fraction of the total mobility benefits that are likely to have occurred through the use of the DMSs. Although project funds and time did not allow for the consideration of those other uses in this analysis, it would be possible to use the values above to extrapolate to those other uses through a comparison of the relative frequencies of those other uses of the DMSs to the frequency of DMS use during incidents under similar time periods when those other uses may have occurred.

Even though the research team was able to generate some estimates of delay reduction benefits, there remain several philosophical issues as to when and how DMS benefits can and should be isolated and evaluated. For example, in situations where traffic demands do not exceed the reduced capacity past an incident, a DMS message about the incident could be considered beneficial if approaching motorists slightly reduced their speed as a safety precaution. In this situation, vehicle delay would actually increase, although the response by the motorist was both appropriate and desired by TxDOT. In other words, it should be remembered that the concept of “benefits” of an individual set of devices such as DMSs are relevant only when considered in context with the objectives for which they are being used. Others have similarly noted the problems with attempting to quantify benefits of DMSs and other types of information technologies in the context of traffic management in a region, to the point where some experts recommend not trying to generate operational benefit estimates of these technologies at all, and recommend relying strictly on customer satisfaction as performance metrics (*50*).

CHAPTER 6: FINAL EVALUATION METHODOLGY

OVERVIEW

Based on the previous discussion, analysis, and lessons learned from the case study validation, it is indicated that DMS performance evaluation is primarily dependent upon three factors:

- environment of DMS application, i.e., urban or rural freeway corridor;
- availability of data necessary for evaluation; and
- limitation to resources available for evaluation, i.e., time and/or manpower.

The environment of application, whether urban or rural, dictates the possible benefits accrued from either delay reduction (enhanced mobility) or crash reduction (safety). The availability of data, before and/or after DMS application, allows or restricts the extent of evaluation. Also, resources within most responsible agencies are always limited.

Therefore, the final evaluation methodology will focus on the most possible benefits to be accrued with reasonably expected evaluation data to be found in the two most common application environments of urban and rural under conditions of limited agency resources. Attention should be given to the previously discussed Figure 1, which provides a summary framework of potential performance metrics utilized in the evaluation of benefits attributable to DMS installation. These performance metrics are segregated by type of data available for analysis and extent of analysis—either quantitative or qualitative.

Qualitative benefit analysis addresses direct measurements of DMS impact on both mobility and safety along a given route, network, or corridor of implementation. Comparisons are made between pre-installation conditions and post-installation conditions to establish mobility and safety benefits demonstrated through congestion/delay and crash reductions and associated cost savings.

Qualitative benefit analyses are directed to establishing DMS influence on driver decisions (and ultimately their quantifiable responses) and motorist opinions about the worth or value of DMS communications. These types of analyses obtain information through motorist behavioral studies that include collecting user panel trip diaries, collecting information elicited from focus groups, or conducting surveys, including attitudinal, opinion, and stated preference approaches.

Further delineations of the final DMS performance evaluation will be divided by the environment of application—urban or rural. Figures 2 and 3, previously shown, illustrate the relationship among DMS application environment (urban/rural), DMS benefits (quantitative/qualitative), and DMS performance metrics.

URBAN DMS METHODOLOGY

Urban applications of DMSs are characterized by extensive deployment coupled with other ITS infrastructure throughout a given corridor or region. Typically, DMS systems in urban environments are heavily utilized for numerous types of motorist communications focusing on incident advisement, construction and maintenance activities, special event traffic management, and travel time (delay) information.

The value (benefits) of these DMS displays may be assessed qualitatively through opinion surveys that establish the utilization of DMS communication to fulfill driver expectations as to message content, timeliness, accuracy, and reliability. The construct of the motorist opinion survey may be as simple as that given in Appendix A or as extensive as that given in Appendix B, which includes questions to assess the potential of driver response for diversion. Administration of the motorist opinion survey to assess DMS performance should be facilitated at a location in proximity to the DMS study route or corridor, which will allow convenient and safe access to drivers exposed to the subject DMS installations such as a driver licensing station, truck stop, or shopping mall. Sample size may vary from 300 to1000 participants depending on time and manpower responses.

Quantitative benefits of DMS performance in urban applications may be established from reduction in traffic crashes or vehicular delay. The former, safety benefits, are difficult to assess in the primary crashes on urban freeways and predominately are a product of high volume or exposure. Those crashes, or reduction in crashes, potentially preventable due to DMS communications, cannot necessarily be determined. Secondary crashes may possibly be isolated and identified; however, this is also very difficult. Reduction in delay may be established dependent upon available data relative to mobility such as entrance/exit/through volumes, speeds (travel time), and length of queues under various incident conditions by location and time of day. However, for a congested urban freeway, the magnitude of the data requirements in this regard is overwhelming unless planned for far in advance of DMS performance assessment. It has also been demonstrated that attempting to assess DMS performance with any type of microscopic network simulation model (VISSIM, CORSIM, etc.) is tedious to calibrate and cost prohibitive in terms of time and manpower to utilize in an urban freeway corridor. However, a more reasonable approach for DMS performance evaluation under urban freeway conditions has been to conduct a macroscopic analysis incorporating a permeability factor to account for diversion influenced by motorist communications. The key to this type of analysis is either the measured, estimated, or assumed diversion potential instituted from DMS incident information displays. The range of this diversion value is from a minimum of 5 percent to a maximum of 15 percent, which is regional, corridor, and site specific.

Utilizing an algorithm of this type, as previously discussed and termed the “permeable pipe” model of macroscopic traffic flow, allows estimates of queue length and vehicle delay within a corridor through repeated additive calculations of various types of incidents by location, time period, duration, and lane closure. Incremental differences may be established between normally expected incident volumes and incident volumes resulting from some percentage of DMS diversion. Applying the current road user cost value ($13.50/vehicle-hour) to that summation of reduction in delay due to specified DMS diversion yields calculated mobility benefits for any particular site, section, or urban freeway corridor. It must be re-emphasized that although this macroscopic analysis procedure or methodology does allow a quantifiable *estimate* of delay reduction benefits resulting from DMS application in an urban freeway corridor, it is limited in scope to response to incidents, which may be a small subset of the total mobility benefits attributable to other communication utilization.

RURAL DMS EVALUATION METHODOLOGY

In contrast to urban DMS applications, implementation of DMSs in rural freeway corridors is limited and more selective for motorist communication to use. The frequency of incidents requiring display of advisory and response information is much less. Congestion levels, whereby demand volume exceeds capacity, are rare, and in many corridors diversion alternatives are limited. Speeds are higher, resulting in higher crash severities. In many instances, weather influences are of greater consequence, necessitating advisories on rural freeways where a DMS is instituted. Rural freeway corridors typically have a higher percentage of truck traffic on interstate routes. Safety benefits (reduced crashes) resulting from DMS deployment are foremost in quantitative performance evaluation on rural freeways.

State crash data should be accessed for both fatal and serious injury crashes for a minimum 3-year period before installation of DMSs along a route or corridor and compared to a similar minimum 3-year period of crashes after installation of DMSs. As discussed previously, adjustments must be made for traffic growth and the statistical significance of the difference in crashes tested as previously shown in Figure 4. Benefits may then be calculated by applying current National Safety Council published costs for traffic crashes by severity category.

Qualitative assessment of DMS performance associated with rural freeway application is affected similarly to that previously stated for urban environments. Motorist opinion surveys, whether given personally, by mail-in postcard, by email response, etc., should solicit information from DMS route or corridor users as to observation, credibility, response potential, operational satisfaction, and economic desire to sustain. Examples of appropriate types of motorist surveys for DMS performance evaluation are in Appendices A and B.

Again, under realistic conditions of limited data availability and agency resources for evaluation (time/manpower), qualitative assessments should not be discounted or understated. Under perceptions and indications of satisfaction with DMSs, performance in fulfilling perceived needs should be weighed heavily as viable benefits to offset costs of DMS installation and maintenance, even if other benefits are non-quantifiable for the reasons previously indicated.

SUMMARY

While deployment of DMS systems in Texas is extensive, with much more planned, this deployment over the past 15 years has been more of a “catch as catch can” with DMSs being integrated into previously staged highway construction and improvement projects. Little thought or preparation was given to future evaluation of these systems. Operations of any individual DMS was initiated under given protocol at a specific time and evolved through the years. Collection and preservation of the data necessary for rigorous pre-post installation evaluation has been sporadic and lacking in consistency. All of these political, situational, and operational factors associated with DMS implementation and operation inhibit the ability to conduct viable quantitative evaluations of DMS performance while increasing the importance and value of benefits associated with qualitative assessments of DMSs.

CHAPTER 7: CONCLUSIONS

The goal of this research project was to provide TxDOT with guidelines and an objective methodological framework for evaluating DMS performance under various levels of data availability and DMS deployment status. To accomplish this, researchers reviewed previous literature regarding DMS evaluation methodologies and results, conducted surveys of TxDOT and other state transportation agency personnel nationally regarding DMS evaluation practices, identified and categorized the various possible performance measures that have or can be used to evaluate DMS performance, proposed an evaluation framework for evaluating DMS benefits, explored the functionality of this proposed framework through a set of case study analyses of DMS implementations in Amarillo and Houston, and revised the framework based on the case study experiences.

One of the main desires for conducting this research was the calculation of DMS benefits that can be quantified in economic terms (i.e., reduced road-user costs via decreased delays, stops, and crashes). In that way, it would be possible for TxDOT to compare such benefits to the costs of DMS deployment in a traditional benefit-cost analysis. Unfortunately, despite the efforts of the research team, it is clear that there still exist significant practical and conceptual limitations to accomplishing this type of analysis.

The practical limitations exist with regards to the application of available traffic simulation models or combined simulation/route choice analysis tools to effectively represent driver diversion responses to DMS information. First, these tools require detailed roadway geometry, traffic signal timing, and traffic volume data on the key routes in the analysis region of interest. In a rural environment such as the Amarillo case study, the model building and calibration effort may be feasible (although still a significant effort); however, in a densely populated urban environment as in the Houston case study, the amount of data and the model-building/calibration effort to represent a single freeway corridor is extremely high. Second, even with a functioning model of a freeway corridor, there exist practical limitations in how best to represent the effects of DMS information in terms of traffic volume changes within the corridor.

Research has shown that drivers adjust their route choices in response to more than just DMS information (i.e., type of trip being made, prior experiences with the DMS information, expectations of conditions on available alternative routes, the presence of queuing conditions themselves on their primary route, etc.). Some insights into likely driver diversion behavior due to DMS information can be obtained by conducting stated preference surveys in the corridor, but the actual responses to such information can differ quite dramatically from these survey responses due to the influences of those other factors already mentioned. As a result, the level of accuracy expected out of this type of analysis does not appear to warrant the time and effort necessary to build, calibrate, and model this behavior. Consequently, simpler analyses such as the permeable pipe model of diversion behavior are more in line with current abilities and understanding of driver diversion responses to DMSs at this time.

Practical limitations also exist with respect to analyzing the safety effects of DMS operations in a corridor. Traffic crashes themselves are highly stochastic and also influenced by many other factors in addition to the presence of DMS information. Efforts to isolate DMS benefits from a safety standpoint typically require several years of crash data before and after installation and also require that no other changes that could affect safety be introduced in the corridor during that time. In an urban environment such as Houston, the ability to control these external influences itself is extremely problematic. One can conduct operational analyses of surrogate measures of safety such as headways or speed changes immediately downstream of a DMS, but the translation between these surrogates and safety improvements is still generally unknown. These practical limitations notwithstanding, it is the conceptual issues associated with estimating DMS benefits that pose even greater challenges. As noted in the Houston case study chapter, one must step back and consider DMS benefits in the context of TxDOT operational goals and strategies in a freeway corridor and/or urban region. DMS messages are intended to provide drivers with better information about current or future travel conditions on a particular roadway.

Research has shown that drivers desire such information, expect it to be credible, and often use it in conjunction with other factors in deciding how to make their trip from origin to destination. It is also apparent that the decisions made by drivers in reaction to such information do not guarantee an improvement in either the individual driver's travel time or the combined effectiveness of all driver decisions collectively. Even so, TxDOT is judged not on the results of the drivers' decisions, but on whether or not the information desired on the DMS is accurate. Warning messages of downstream conditions may not only generate diversion, but may improve driver preparedness for the downstream traffic slowdown and lead to slightly lower approach speeds.

While a desirable outcome of the information (and appreciated by drivers), the end result on operations would be an increase in travel time and road-user costs according to traditional analysis methodologies. Presumably, the change in behavior would lead to improved safety, but as noted above, the ability of the analyst to determine this benefit in an urban region would be problematic as well.

Ultimately, the conceptual and practical challenges associated with DMS benefit estimation argue strongly for the use of non-economic measures of performance. Indicators such as driver satisfaction with the information, usage statistics, and similar measures are more directly attributable to TxDOT's goals and objectives for DMS operation. While such measures cannot be assigned monetary values as easily as other measures such as travel time and crashes, the research team strongly believes they are more appropriate and beneficial. As also noted previously, other experts in the area of ITS benefit estimation also believe that DMS operations should not be evaluated independently of other components of an overall freeway management system (*x*). To do so is akin to trying to evaluate the economic benefits of constructing a set of columns on which to set the deck of a new or reconstructed bridge. Without the deck (and without the pavement leading up to the deck), one is hard pressed to determine what the economic benefit to travelers is for the columns. Consequently, one must consider the entire bridge structure together when computing traveler benefits. In a similar vein, it is the overall effect of a freeway management system (including surveillance, incident response, ramp metering, DMS operations, etc.) that should be measured and evaluated in terms of overall economic benefits and other measures used to evaluate and monitor the effectiveness of individual components such as DMSs.

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APPENDIX A

MOTORIST OPINION SURVEY

Figure A-1. Motorist Opinion Survey.

Texas Department of Transportation

Motorist Survey

Please answer all of the following questions.

YOUR OPINIONS ARE IMPORTANT TO US!

1. How often do you travel on either Interstate 40 and/or Interstate 27/US Highway 287?

___ Daily
___ Weekly
___ Monthly
___ Less than Monthly
___ Never ⇒ If you answered never, please **STOP** here. Thank you for your time.

2. What kind of vehicle do you drive most often on Interstate 40 and/or Interstate 27/US Highway 287?

___ Car/Pickup/SUV
___ Small Service/Delivery Truck
___ Long-Haul 18-Wheeler

3. Have you ever seen electronic messages displayed on roadway information signs on I-40 and/or I-27/US Highway 287?

___ Yes
___ No

4. On I-40 and/or I-27/US Highway 287, the electronic roadway message signs usually show warnings for ________.

___ Weather-Related Advisory Activities
___ Accidents and/or Road Hazard Warnings
___ Construction/Maintenance
___ Road Closure and/or Detour
___ Other *(please specify)* ________________________________

5. What information would be most important to you to be displayed on an electronic roadway message sign? (Rate 1-4 with 1 being the most important)

   ___ Weather-Related Advisory Activities
   ___ Construction/Maintenance
   ___ Accidents/Road Hazard Warnings
   ___ Road Closure and/or Detour
   ___ Other *(please specify)* ____

6. Do you read the electronic messages posted on roadway information signs?

   ___ Always or Most of the Time
   ___ Sometimes
   ___ Rarely or Never

7. Have you ever turned your radio to a posted frequency to get roadway information?

   ___ Yes ⇒ ⇒ ⇒
   ___ No

   7a. Was the information helpful?
   ___ Yes
   ___ No

8. Have you ever used a cell phone to get road information while traveling?

   ___ Yes
   ___ No

9. Is the information posted on electronic roadway message signs accurate?

   ___ Yes
   ___ No ⇒ ⇒ ⇒

   9a. How often is information inaccurate?
   ___ Usually ___Sometimes ___ Rarely

Please indicate how strongly you agree or disagree with the following statements.
The choices are:
Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A), and Strongly Agree (SA).

CIRCLE ONE

10. Overall, the implementation of electronic roadway message signs on I-40 and I-27 has been positive. SD D N A SA

11. Electronic roadway messages have personally helped me while traveling. SD D N A SA

12. Roadways are safer as a result of electronic roadway message signs. SD D N A SA

13. I would like to see more electronic roadway message signs in the future. SD D N A SA

14. For comparison purposes, please tell us your gender, age group, and educational attainment.

___ Male
___ Female

___ 16-25 years
___ 26-65 years
___ Over 65 years

___ Less than high school
___ High school diploma
___ College or associate’s degree
___ Graduate degree(s)

APPENDIX B

DRIVER PERCEPTION AND RESPONSE TO DYNAMIC MESSAGE SIGNS ALONG I-45 CORRIDOR IN HOUSTON, TEXAS

INTRODUCTION

The objective of Research Project 0-4772, "Methods and Guidelines for Evaluating Dynamic Message Sign Performance," is to develop a methodology to estimate potential savings in terms of congestion and traffic delays from the use of DMSs on Texas roadways. DMS systems communicate up-to-date, accurate, and pertinent travel information to drivers through electronic signs on roadways. Motorists can use the information to avoid hazards or delays and respond to changing roadway conditions.

As part of the research effort, the Texas Transportation Institute conducted driver questionnaire surveys in Amarillo and Houston, Texas, to better understand driver awareness of and response to DMS messages in terms of inducing route changes. The results from the Amarillo survey are presented under separate cover, *Amarillo Dynamic Message Signs (DMS) Motorist Survey*. This report summarizes the Houston driver survey results.

METHODS

Surveys were administered to drivers visiting the Department of Public Safety Driver License Office at 4545 Dacoma in Houston during a two-week period in March 2005. Every effort was made to recruit as many respondents as possible; thus, randomness of selection was sacrificed in order to maximize the sample size.

Surveyors approached potential respondents and assessed their willingness to participate in the brief survey. If the person agreed, surveyors asked a screening question to determine if the person used the North Freeway (I-45N) to travel. A total of 594 persons indicated driving on the North Freeway and were included in the sample. Of the 1473 drivers approached to participate in the survey, about one-third did not qualify (31 percent) and 28.5 percent refused to participate. Surveyors verbally asked questions and recorded responses on the questionnaire.

The stated-preference driver questionnaire consisted of two parts: a series of questions about roadway travel, dynamic message signs, and demographics; and a series of hypothetical questions about travel choices under different scenarios. Each driver questionnaire contained one of two possible scenarios with four questions about each scenario. Different scenario locations were used, and there were different response categories for the two scenarios. Question order was varied, but the route choice options remained constant for each survey type. Question content also differed by time (“during the morning rush hour” or “after the morning rush hour”), by traffic volume (“not too much traffic” or “quite a lot of traffic”), message source (“hear a radio report” or “see electronic sign”), and location (Crosstimbers or Beltway 8). Surveyors had respondents look at a card while reading the four hypothetical questions aloud and pointed to photos to illustrate lane position and traffic volumes.

Example Scenario “A” Statement (4 Total)

You are driving south on the North Freeway, in the 2nd lane from the right, **after the morning rush hour.** As shown in the picture above, you are just north of the Airline Drive exit. The road is dry and visibility is good, and there’s **not too much traffic**—about like it shows in the picture. After you pass the Airline exit, you **see an electronic sign** that looks like this:

MAJOR ACCIDENT AT
CROSSTIMBERS

2 LANES CLOSED

Scenario “A” Questions

A-1 Not too much traffic; after Airline Dr., see electronic sign; “Major Accident at Crosstimbers—2 Lanes Closed.” What would you do? Would you:
A-2 Quite a lot of traffic; after Airline Dr., hear a radio report; “Major Accident at Crosstimbers—2 Lanes Closed.” What would you do? Would you:
A-3 Not too much traffic; after Airline Dr., hear a radio report; “Major Accident at Crosstimbers—2 Lanes Closed.” What would you do? Would you:
A-4 Quite a lot of traffic; after Airline Dr., see electronic sign; “Major Accident at Crosstimbers—2 Lanes Closed.” What would you do? Would you:

Scenario "A" Travel Choice Alternatives

A. Stay in your lane and continue on to your planned exit.

B. Move to the right lane and continue on to your planned exit.

C. Exit the freeway at Crosstimbers and continue on the frontage road.

D. Exit the freeway at Crosstimbers and then get off the frontage road and take a different route to your destination.

Example Scenario "B" Statement (4 Total)

You are driving south on the North Freeway, in the 2nd lane from the right, **after the morning rush hour.** As shown in the picture above, you are just north of the Rankin Road exit. The road is dry and visibility is good, and there's not **too much traffic**—about like it shows in the picture. After you pass the Airline exit, **you see an electronic sign** that looks like this:

MAJOR ACCIDENT
AT BLTWY 8

2 LANES CLOSED

Scenario "B" Questions

B-1: Not too much traffic; after Rankin Rd. exit, see electronic sign; "Major Accident at Beltway 8—2 Lanes Closed. What would you do? Would you:

B-2: Quite a lot of traffic; after Rankin Rd. exit, hear a radio report; "Major Accident at Beltway 8—2 Lanes Closed." What would you do? Would you:

B-3 Not too much traffic; after Rankin Rd. exit, hear a radio report; "Major Accident at Beltway 8—2 Lanes Closed." What would you do? Would you:

B-4 Quite a lot of traffic; after Rankin Rd. exit, see electronic sign; "Major Accident at Beltway 8—2 Lanes Closed." What would you do? Would you:

Scenario "B" Travel Choice Alternatives

A. Stay in your lane and continue on to your planned exit.
B. Move to the right lane and continue on to your planned exit.
C. Exit the freeway at Greens Rd. and continue on the frontage road.
D. Exit the freeway at Greens Rd. and then get off the frontage road and take a different route to your destination.
E. Exit the freeway at Beltway 8 and continue on the frontage road.
F. Exit the freeway at Beltway 8 and then get off the frontage road and take a different route to your destination.

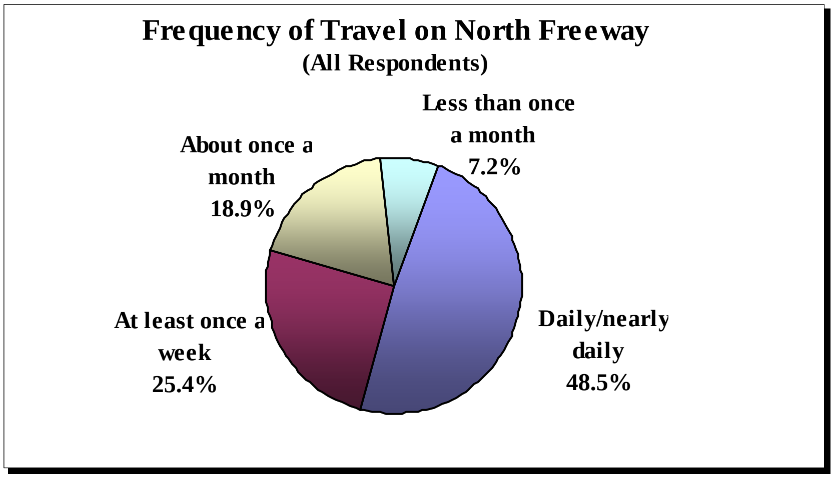
Respondents were shown a map of the area as a visual reference for questions about trip origin and destination and for the hypothetical scenarios. A total of 293 drivers completed Scenario "A" surveys and are referred to as Group "A." Those completing Scenario "B" surveys are referred to as Group "B" and include a total of 301 drivers.

RESULTS

The survey sample included a total of 594 respondents who indicated that they drive on I-45N in Houston, Texas. Standard frequency distributions and cross tabulations were computed and results compiled for all survey respondents. Results are reported on driver vehicle and travel characteristics, driver awareness and perception of DMS messages, and driver response to messages, both DMS and radio, during peak and non-peak traffic conditions. Demographic information for survey respondents is also presented.

Travel Information

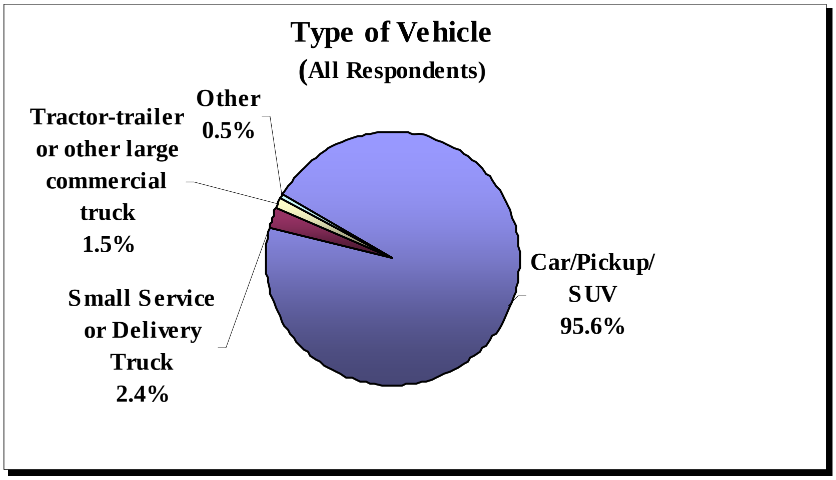
As Figure B-1 shows, almost three-fourths of the survey respondents (73.9 percent) said that they were frequent users, traveling on I-45 at least once a week (25.4 percent) or daily (48.5 percent). Almost one-fifth of the respondents use the roadway about once a month (18.9 percent).



Source: Texas Transportation Institute survey conducted March 2005.

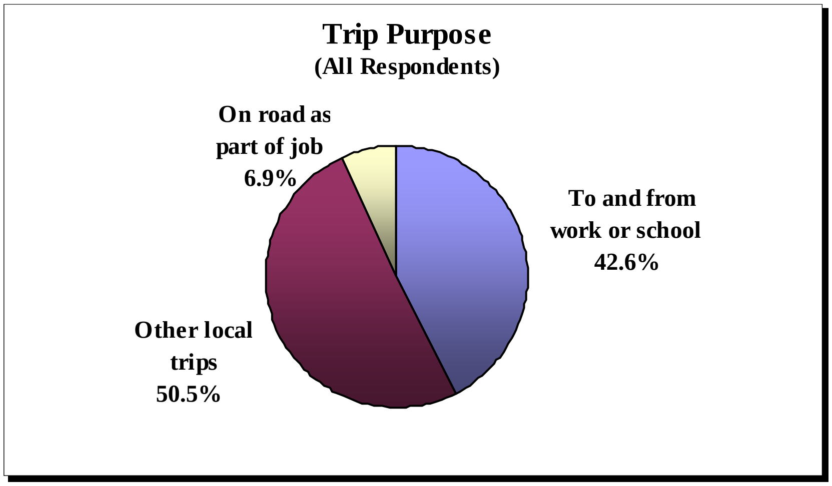
Figure B-1. Frequency of Travel on North Freeway, All Respondents.

Most respondents (95.6 percent) usually drive a car, pickup truck, or a sports utility vehicle while traveling on I-45 (see Figure B-2). The predominant reason for driving on I-45 was to make local trips such as shopping, medical, and other errands (50.5 percent). A total of 253 respondents, or 42.6 percent, indicated traveling to and from work or school on the North Freeway, while 6.9 percent said they drive on I-45 as part of their job (see Figure B-3).



Source: Texas Transportation Institute survey conducted March 2005

Figure B-2. Type of Vehicle, All Respondents.



Source: Texas Transportation Institute surveyed conducted March 2005

Figure B-3. Trip Purpose, All Respondents.

Respondents were asked about how often they traveled from Richey Road, an east-west arterial road near the origin of the I-45N corridor study area, to downtown Houston (see Table B-1). More than one-half of all respondents (55.2 percent) indicated traveling the area "sometimes" (32.9 percent) or "very often" (22.3 percent). The percentage increased to 62.5 percent among regular road users.

Table B-1. Frequency of Travel on I-45N between Richey Road and Downtown Houston.

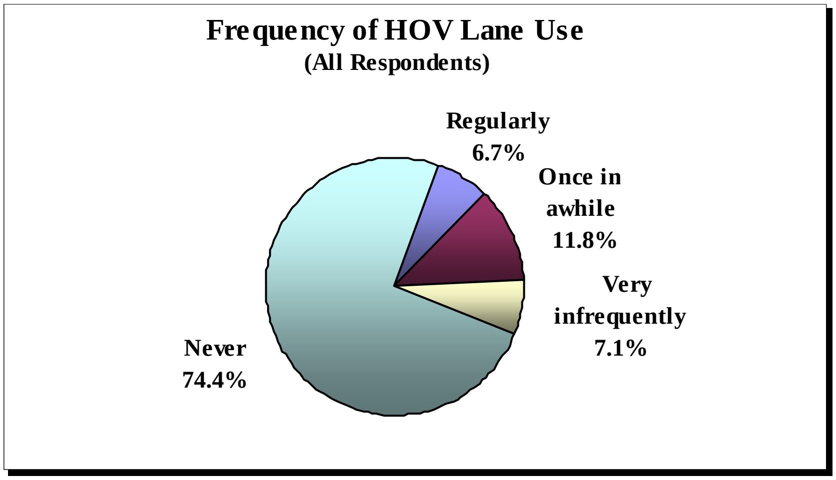
	All Respondents		Regular Road Users*		Group "A" Crosstimbers		Group "B" Beltway 8	
Frequency	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Very often	131	22.3	120	27.6	64	22.1	67	22.6
Sometimes	193	32.9	152	34.9	100	34.5	93	31.3
Rarely	130	22.2	80	18.4	67	23.1	63	21.2
Never	133	22.6	83	19.1	59	20.3	74	24.9
Total	**587**	**100.0**	**435**	**100.0**	**290**	**100.0**	**297**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

As Figure B-4 indicates, the majority of respondents said that they never use high occupancy vehicle lanes while driving on the North Freeway (74.4 percent). One-fifth (18.5 percent) of all respondents traveling to work or school use HOV lanes "regularly" or "once in awhile." Table B-2 summarizes the frequency of HOV lane use for all survey respondents, regular road users, and Group "A" and Group "B" survey respondents.

Respondents who indicated that they travel on the North Freeway daily or at least once a week are defined as "regular road users" (n=439). Almost all regular road users drive personal cars, pickups, or sports utility vehicles (94.3 percent) and are more likely to use I-45 for commute trips (54.2 percent) or while shopping, running errands, or going to medical appointments (38.0 percent). Ninety-four percent of commute trips and more than one-half (55.7 percent) of all local trips were made by respondents considered to be regular road users. Table B-3 shows the summary of road user characteristics for all survey respondents, regular road users, and Group "A" and Group "B" survey respondents.



Source: Texas Transportation Institute survey conducted March 2005

Figure B-4. HOV Lane Use, All Respondents.

Table B-2. Frequency of HOV Lane Use.

	All Respondents		Regular Road Users*		Group "A" Crosstimbers		Group "B" Beltway 8	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Regularly	40	6.7	34	7.7	17	5.8	23	7.6
Once in a while	70	11.8	55	12.5	37	12.6	33	11.0
Very infrequently	42	7.1	24	5.5	16	5.5	26	8.6
Never	442	74.4	326	74.3	223	76.1	219	72.8
Total	**594**	**100.0**	**439**	**100.0**	**293**	**100.0**	**301**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

Table B-3. Summary of Road User Characteristics.

	All Respondents		Regular Road Users*		Group "A" Crosstimbers		Group "B" Beltway 8	
Characteristic	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Frequency of Travel								
Daily/nearly daily	288	48.5	88	65.6	142	48.5	146	48.5
At least once a week	151	25.4	51	34.4	77	26.3	74	24.6
About once a month	112	18.9	0	0.0	62	21.2	50	16.6
Less than once a month	43	7.2	0	0.0	12	4.0	31	10.3
Total	**594**	**100.0**	**39**	**100.0**	**293**	**100.0**	**301**	**100.0**
Type of Vehicle								
Car/pickup/SUV	568	95.6	414	94.3	281	95.9	287	95.4
Small service or delivery truck	14	2.4	14	3.2	5	1.7	9	2.9
Tractor-trailer or other large commercial truck	9	1.5	8	1.8	4	1.4	5	1.7
Other	3	0.5	3	0.7	3	1.0	0	0.0
Total	**594**	**100.0**	**439**	**100.0**	**293**	**100.0**	**301**	**100.0**
Trip purpose								
To and from work or school	253	42.6	238	54.2	128	43.7	125	41.5
Other local trips	300	50.5	167	38.0	151	51.5	49	49.5
On road as part of job	41	6.9	34	7.8	14	4.8	27	9.0
Total	**594**	**100.0**	**439**	**100.0**	**293**	**100.0**	**301**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

DMS Exposure and Perceptions

Regarding prior exposure to DMSs on the North Freeway, a total of 572, or 96.3 percent, of the respondents reported that they had previously viewed DMS messages (see Table B-4). In terms of how often respondents indicated reading the information on the DMS, almost 8 out of 10, or 77.9 percent, said that they always read messages displayed on the signs (see Table B-5).

Respondents were asked to rate the accuracy of the information posted on the electronic message signs (see Table B-6). The majority of respondents considered DMS messages to be accurate most of the time (73.8 percent), while 23.9 percent considered them accurate some of the time.

Table B-4. Prior Observation of DMS Messages.

	All Respondents		**Regular Road Users***		**Group "A" Crosstimbers**		**Group "B" Beltway 8**	
Previously Viewed DMS Messages	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Yes	572	96.3	426	97.0	285	97.3	287	95.3
No	22	3.7	13	3.0	8	2.7	14	4.7
Total	**594**	**100.0**	**439**	**100.0**	**293**	**100.0**	**301**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

Table B-5. How Often DMS Messages Read.

How Often Message Read	All Respondents		Regular Road Users*		Group "A" Crosstimbers		Group "B" Beltway 8	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Always	445	77.9	340	80.0	227	79.7	218	76.2
Usually	80	14.0	57	13.4	38	13.3	42	14.7
Sometimes	35	6.1	23	5.4	14	4.9	21	7.3
Rarely	10	1.8	5	1.2	6	2.1	4	1.4
Never	1	0.2	0	0.0	0	0.0	1	0.4
Total	**571**	**100.0**	**425**	**100.0**	**285**	**100.0**	**286**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

Table B-6. Accuracy of Messages Read.

	All Respondents		Regular Road Users*		Group "A" Crosstimbers		Group "B" Beltway 8	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Usually	418	73.8	304	71.9	191	67.7	227	79.7
Sometimes	136	23.9	110	26.0	82	29.1	54	18.9
Rarely	13	2.3	9	2.1	9	3.2	4	1.4
Total	**567**	**100.0**	**439**	**100.0**	**282**	**100.0**	**285**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

Other Sources of Traffic Information

The radio is the most popular source of traffic information because most drivers have in-car radios. In general, respondents were more likely to get traffic information from messages displayed on DMSs than by listening to the radio. Less than one-third of the respondents

(27.7 percent) indicated that they "always" or "almost always" listen to the radio for road and traffic reports while driving on I-45 (see Table B-7). Almost one-half of the respondents never listen to the radio for traffic reports (39.2 percent) or tune in only if the traffic is worse than usual (10.7 percent).

Driver Response to Freeway Incidents

The survey addressed driver response to radio broadcast and DMS messages about a traffic accident and lane closure on the North Freeway during peak and non-peak travel times. The "peak" period was presented to respondents as "during the morning rush hour" and "much more traffic." "Non-peak" was presented as "after the morning rush hour" and "not too much traffic."

Radio Broadcast Messages

Most drivers in both groups indicated that they would respond in some way (i.e., either move to the right lane or exit the freeway) after hearing a radio broadcast message about accident delays and lane closure on the North Freeway (see Tables B-8 and B-9). Responses differed, however, based on whether the incident occurred during peak or non-peak travel periods.

Table B-7. How Often Listen to Radio and Traffic Reports While Driving on I-45.

	All Respondents		**Regular Road Users**		**Group "A" Crosstimbers**		**Group "B" Beltway 8**	
How Often Listen	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Always/almost always	163	27.7	126	28.9	79	27.1	84	28.3
Usually	50	8.5	38	8.9	22	7.5	28	9.4
Occasionally	82	13.9	65	14.9	38	13.0	44	14.8
Only if traffic worse than usual	63	10.7	41	9.4	36	12.3	27	9.1
Never	231	39.2	165	37.9	117	40.1	114	38.4
Total	**589**	**100.0**	**435**	**100.0**	**292**	**100.0**	**297**	**100.0**

Source: Texas Transportation Institute survey conducted March 2005

Table B-8. Driver Response to Incident Information: Radio Broadcast, Group "A."

	Non-peak				Peak			
	All Respondents		Regular Road Users*		All Respondents		Regular Road Users*	
Route choice	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Stay in lane and continue on to planned exit	132	45.2	96	44.0	73	25.0	48	22.0
Move to the right lane and continue to planned exit	50	17.2	35	16.1	38	13.0	28	12.9
Exit the freeway at Crosstimbers and continue on the frontage road	55	18.8	40	18.4	68	23.3	50	22.9
Exit the freeway at Crosstimbers and then get off the frontage road and take a different route to final destination	55	18.8	47	21.5	113	38.7	92	42.2
Total	**292**	**100.0**	**218**	**100.0**	**292**	**100.0**	**218**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

During non-peak travel periods, the majority of drivers indicated that they would stay on the freeway and either continue driving in the same lane or move to the right while continuing on to their planned exit (62.4 percent Group "A" and 61.1 percent Group "B").

Among Group "A" drivers indicating that they would exit the freeway, an equal percentage (18.8 percent) said that they would exit at Crosstimbers and continue on the frontage road; or they would exit the freeway, get off the frontage road, and take a different route to their final destination.

Table B-9. Driver Response to Incident Information: Radio Broadcast, Group "B."

	Non-peak				Peak			
	All Respondents		Regular Road Users*		All Respondents		Regular Road Users*	
Route choice	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Stay in lane and continue on to planned exit	137	46.0	97	44.5	77	25.8	54	24.9
Move to the right lane and continue to planned exit	45	15.1	32	14.7	38	12.8	25	11.5
Exit the freeway at Greens Road and continue on the frontage road	52	17.5	43	19.7	69	23.2	57	26.3
Exit the freeway at Greens Road and then get off the frontage road and take a different route than final destination	53	17.8	39	17.9	89	29.8	68	31.3
Exit the freeway at Beltway 8 and continue on the frontage road	3	1.0	2	0.9	11	3.7	8	3.7
Exit the freeway at Beltway 8 and then get off the frontage road and take a different route to final destination	8	2.6	5	2.3	14	4.7	5	2.3
Total	**298**	**100.0**	**218**	**100.0**	**298**	**100.0**	**217**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

Among Group "B" drivers, an almost equal percentage also said that they would likely exit at Greens Road and continue on the frontage road (17.5 percent); or exit at Greens Road, get off the frontage road, and take a different route to their final destination (17.8 percent). Few drivers indicated that they would exit the freeway at Beltway 8 regardless of the travel period (see Table B-9).

During peak travel periods, respondents in both groups were more likely to exit the freeway when hearing a radio broadcast message about potential delays and lane closure caused by an accident (62 percent Group “A” and 61.4 percent Group “B”). There were similarities in terms of what drivers in both groups said they would do once they exited the freeway. A larger percentage of drivers in Group “A” said they would exit the freeway at Crosstimbers, get off the frontage road, and take a different route to their final destination (38.7 percent) compared to drivers who would exit the freeway and continue on the frontage road (23.3 percent) (see Table B-8). Group “B” drivers were also more likely to exit at Greens Road, get off the frontage road, and take a different route to their final destination (29.8 percent) rather than exit at Greens Road and continue on the frontage road (23.2 percent), exit at Beltway 8, and continue on the frontage road (3.7 percent), or exit at Beltway 8, get off the frontage road, and take a different route to their final destination (4.7 percent) (see Table B-9). Regular road users were more likely to exit the freeway when hearing a radio broadcast message about a freeway incident compared to all respondents during both peak and non-peak travel times.

DMS Messages

The primary objective of DMSs is to divert traffic flow in the event of a freeway incident through the use of alternative routes. There appears to be very little difference among respondents in their decision to continue driving on the North Freeway or to exit the freeway and take a different route, regardless of how they received the incident information (i.e., radio broadcast or DMS). Most drivers in both groups indicated that they would respond in some way (i.e., either move to the right lane or exit the freeway) after seeing a DMS message about accident delays and lane closure on the North Freeway (see Tables B-10 and B-11). As with radio broadcast messages, responses differed based on whether the incident occurred during peak or non-peak travel periods.

Table B-10. Driver Response to Incident Information: DMS Message, Group "A."

	Non-peak				Peak			
	All Respondents		Regular Road Users*		All Respondents		Regular Road Users*	
Route choice	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Stay in lane and continue on to planned exit	126	43.2	87	39.9	67	23.0	47	21.6
Move to the right lane and continue to planned exit	53	18.2	45	20.6	44	15.0	31	14.2
Exit the freeway at Crosstimbers and continue on the frontage road	52	17.8	40	18.4	71	24.3	54	24.8
Exit the freeway at Crosstimbers and then get off the frontage road and take a different route to final destination	61	20.8	46	21.1	110	37.7	86	39.4
Total	**292**	**100.0**	**218**	**100.0**	**292**	**100.0**	**218**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

During non-peak travel periods, the majority of drivers indicated that they would stay on the freeway and either continue driving in the same lane or move to the right while continuing on to their planned exit (61.4 percent in Group "A" and 61.5 percent in Group "B").

Among Group "A" drivers indicating that they would exit the freeway, 20.8 percent said that they would exit at Crosstimbers, get off the frontage road, and take a different route to their final destination compared to 17.8 percent who would exit and continue on the frontage road.

Among Group "B" drivers, an almost equal percentage said that they would likely exit at Greens Road and continue on the frontage road (17.5 percent) or get off the frontage road and take a different route to their final destination (17.2 percent). Few drivers indicated that they would exit the freeway at Beltway 8 regardless of the travel period (3.8 percent).

Table B-11. Driver Response to Incident Information: DMS Message, Group "B."

	Non-peak				Peak			
	All Respondents		Regular Road Users*		All Respondents		Regular Road Users*	
Route choice	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Stay in lane and continue on to planned exit	131	44.0	93	42.9	73	24.6	54	24.9
Move to the right lane and continue to planned exit	52	17.5	37	17.1	36	12.1	25	11.5
Exit the freeway at Greens Road and continue on the frontage road	52	17.5	41	18.8	67	22.6	57	26.3
Exit the freeway at Greens Road and then get off the frontage road and take a different route than final destination	51	17.2	38	17.5	95	32.0	68	31.3
Exit the freeway at Beltway 8 and continue on the frontage road	4	1.4	3	1.4	11	3.6	8	3.7
Exit the freeway at Beltway 8 and then get off the frontage road and take a different route to final destination	7	2.4	5	2.3	15	5.1	5	2.3
Total	**297**	**100.0**	**217**	**100.0**	**297**	**100.0**	**217**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

During peak travel periods, respondents in both groups were more likely to exit the freeway when seeing a DMS message about potential delays and lane closure due to an accident (62 percent in Group "A" and 63.3 percent in Group "B"). There were similarities in terms of what drivers in both groups said they would do once they exited the freeway. A larger percentage of drivers in Group "A" said they would exit the freeway at Crosstimbers, get off the frontage road, and take a different route to their final destination (37.7 percent) compared to drivers who would exit the freeway and continue on the frontage road (24.3 percent). Group "B" drivers were also more likely to exit at Greens Road, get off the frontage road, and take a different route to their final destination (32.0 percent) rather than exit at Greens Road and continue on the frontage road (22.6 percent); exit at Beltway 8 and continue on the frontage road (3.6 percent); or exit at Beltway 8, get off the frontage road, and take a different route to their final destination (5.1 percent). Regular road users were more likely to exit the freeway when seeing a DMS message about a freeway incident compared to all respondents during both peak and non-peak travel times.

Trip Purpose and Travel Period

Data for both groups were combined and analyzed to determine differences in driver route choices based on trip purpose. Survey responses for "stay in lane" and "move to the right lane" were collapsed into one category. All responses indicating that the driver would exit the freeway were also combined. Table B-12 presents cross tabulations. Drivers who travel on the North Freeway to work or school and hear a radio broadcast or see a DMS message about travel delays caused by a freeway incident are more likely to divert from the freeway during peak travel periods compared to drivers making other non-commute trips. Drivers traveling for shopping, medical or other local trips are more likely to exit the freeway in response to radio and DMS messages during peak periods compared to those driving as part of their job. Less than one out of four drivers indicated that they would divert from the freeway in response to radio or DMS messages about freeway incidents during non-peak times. There was no variation among drivers based on trip purpose.

Table B-12. Percent of Drivers Indicating That They Would Divert from Freeway by Trip Purpose and Travel Time.

	Saw DMS Message			
	Non-peak		Peak	
Trip Purpose	**(n)**	**(%)**	**(n)**	**(%)**
To and from work	97	39.0	165	66.3
Part of job	15	38.0	21	53.0
Other local	115	38.3	183	61.0
Total	**227**		**369**	
	Heard Radio Message			
	Non-peak		**Peak**	
Trip Purpose	**(n)**	**(%)**	**(n)**	**(%)**
To and from work	96	38.4	159	63.9
Part of job	14	35.0	20	48.8
Other local	116	38.7	185	61.7
Total	**226**		**364**	

Source: Texas Transportation Institute survey conducted March 2005

Demographic Information

Demographic data collected during the survey include age, gender, and educational level of the respondent and are presented graphically in Tables B-13 through B-15. Among all survey respondents, 71.8 percent were between the ages of 26 and 65 years. The majority of survey respondents were male (54.4 percent), and similar percentages completed some college (22.1 percent) or had a college degree (23.7 percent). Although age and gender are similar, the proportion of regular road users indicating that they have college or advanced degrees is higher compared to all survey respondents.

Table B-13. Respondent Age.

Age Group	All Respondents (n)	All Respondents (%)	Regular Road Users (n)	Regular Road Users (%)	Group “A” (n)	Group “A” (%)	Group “B” (n)	Group “B” (%)
Under 18 years	9	1.5	6	1.4	5	1.7	4	1.3
18 – 25 years	139	23.4	114	26.0	71	24.2	68	22.6
26 – 65 years	426	71.8	308	70.1	210	71.7	217	72.1
Over 65 years	14	2.4	7	1.6	6	2.1	8	2.7
Unknown	5	0.9	4	0.9	1	0.3	4	1.3
Total	**593**	**100.0**	**439**	**100.0**	**293**	**100.0**	**301**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

Table B-14. Respondent Gender.

Gender	All Respondents (n)	All Respondents (%)	Regular Road Users* (n)	Regular Road Users* (%)	Group “A” (n)	Group “A” (%)	Group “B” (n)	Group “B” (%)
Male	323	54.4	248	56.5	164	56.0	159	52.8
Female	266	44.8	187	42.6	128	43.7	138	45.9
Unknown	5	0.8	4	0.9	1	0.3	4	1.3
Total	**594**	**100.0**	**439**	**100.0**	**293**	**100.0**	**301**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

Table B-15. Respondent Education.

	All Respondents		Regular Road Users*		Group "A"		Group "B"	
Age Group	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**	**(n)**	**(%)**
Less than high school	78	13.1	59	13.4	42	14.3	36	12.0
High school diploma	179	30.1	101	23.0	69	23.6	72	23.9
Completed some college	131	22.1	27	6.2	31	10.6	29	9.6
College or associate's degree	141	23.7	152	34.6	81	27.6	98	32.6
Graduate or professional degree(s)	60	10.1	96	21.9	69	23.6	62	20.6
Unknown	5	0.9	4	0.9	1	0.3	4	1.3
Total	**594**	**100.0**	**439**	**100.0**	**293**	**100.0**	**301**	**100.0**

* Consists of respondents indicating that they travel the roadway daily or at least once a week

Source: Texas Transportation Institute survey conducted March 2005

SUMMARY

The survey was intended to determine driver response to radio broadcast and DMS messages about freeway incidents and lane closures in terms of inducing route changes. Almost three-fourths of the survey respondents said that they were frequent travelers on I-45 (73.9 percent). Most usually drive I-45N in a car, pickup truck, or SUV (95.6 percent) for local trips (50.5 percent), work or school related (42.6 percent), and as part of their job (6.9 percent).

Most respondents said that they never use HOV lanes while driving on the North Freeway (74.4 percent). An overwhelming majority of survey respondents (96.3 percent) indicated seeing DMS messages, and most said that they always read the messages (77.9 percent). Three-fourths of the respondents felt that the DMS messages were usually accurate (73.8 percent). Less than one-third of the respondents indicated that they almost always listen to the radio for road and traffic reports while driving on I-45N (27.7 percent).

Most respondents indicated that they would respond in some way when hearing a radio broadcast or seeing a DMS message about an accident on the North Freeway. During non-peak travel periods, the majority of drivers indicated that they would stay on the freeway and either continue driving in the same lane or move to the right while continuing on to their planned exit in response to both radio broadcast and DMS messages.

During peak travel periods, respondents were more likely to exit the freeway in response to radio broadcast and DMS messages about potential delays and lane closure due to an accident. Similar trends were observed among the groups regardless of the source of the message (radio or DMS). Regular road users were more likely to exit the freeway when hearing a radio broadcast or seeing a DMS about a freeway incident compared to all respondents during both peak and non-peak travel times. Drivers who travel on the North Freeway to work or school and hear a radio broadcast or see a DMS message about travel delays caused by a freeway incident are more likely to divert from the freeway during peak travel periods compared to drivers making other non-commute trips. Less than one out of four drivers indicated that they would divert from the freeway in response to radio or DMS messages about freeway incidents during non-peak times regardless of trip purpose.

APPENDIX C

HOUSTON CASE STUDY

Table C-1. 2004 Incidents I-45 Northbound I-610 to North Shepard.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage	9	3	4	1	
	1 of 4	5	1	1	1	1
	2 of 4	5	4	4		
	3 of 4	1	1			
	4 of 4					
6A – 9A	Shoulder Blockage	3	3	2		
	1 of 4	5	4	6	1	
	2 of 4	5	5	4	1	
	3 of 4	2		1	2	
	4 of 4					
9A – 3P	Shoulder Blockage	11	11	10	5	
	1 of 4	25	13	11	5	
	2 of 4	15	5	5	1	
	3 of 4	2	2	1		
	4 of 4					
3P – 7P	Shoulder Blockage	12	13	11	3	2
	1 of 4	32	12	6	2	
	2 of 4	6	9	6	2	
	3 of 4	2		2		
	4 of 4		1		1	
7P – 12A	Shoulder Blockage	4	3	3		1
	1 of 4	10	5	3	1	
	2 of 4	7	6	3		1
	3 of 4	1	4			
	4 of 4					

Table C-2. 2004 Incidents I-45 Northbound North Shepard to Beltway 8.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage	1		3		1
	1 of 4	1	1	1		
	2 of 4	1		1		
	3 of 4			1		
	4 of 4					
6A – 9A	Shoulder Blockage	4	1	2		
	1 of 4	2				
	2 of 4		1	1	1	
	3 of 4					
	4 of 4					
9A – 3P	Shoulder Blockage	5	2	4		
	1 of 4	4	6	1		
	2 of 4			1		
	3 of 4					
	4 of 4					
3P – 7P	Shoulder Blockage	4	3	2	1	
	1 of 4	2	4	4	1	
	2 of 4			1		
	3 of 4		1			
	4 of 4					
7P – 12A	Shoulder Blockage	1		1		1
	1 of 4	1	1	1		
	2 of 4	1		1	1	
	3 of 4					
	4 of 4					

Table C-3. 2004 Incidents I-45 Northbound Beltway 8 to Cypresswood.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage	5	1	3	2	
	1 of 4		1		1	
	2 of 4	1		1		
	3 of 4	1		2		
	4 of 4					
6A – 9A	Shoulder Blockage	1	1	2	1	
	1 of 4	4	3			
	2 of 4		2	1		
	3 of 4	1				
	4 of 4					
9A – 3P	Shoulder Blockage	3	3	4	2	
	1 of 4	1	1	4		
	2 of 4		2	1		
	3 of 4	1		1		
	4 of 4					
3P – 7P	Shoulder Blockage	8	4	5		
	1 of 4	1	3	1		
	2 of 4		2	1		
	3 of 4					
	4 of 4					
7P – 12A	Shoulder Blockage	1		1		
	1 of 4		2			
	2 of 4	1				
	3 of 4	1		1		
	4 of 4					

Table C-4. 2004 Incidents I-45 Northbound Cypresswood to Hardy Toll Road.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage					
	1 of 4					
	2 of 4					
	3 of 4					
	4 of 4					
6A – 9A	Shoulder Blockage	3				
	1 of 4			1		
	2 of 4		1			
	3 of 4					
	4 of 4					
9A – 3P	Shoulder Blockage	2	2	2		1
	1 of 4			1		
	2 of 4		1			
	3 of 4					
	4 of 4					
3P – 7P	Shoulder Blockage	2	2			
	1 of 4	1	2			
	2 of 4					
	3 of 4					
	4 of 4					
7P – 12A	Shoulder Blockage				2	
	1 of 4					
	2 of 4					
	3 of 4		1			
	4 of 4		1			

Table C-5. 2004 Incidents I-45 Southbound Hardy Toll Road to Cypresswood.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage					
	1 of 4					
	2 of 4					
	3 of 4					
	4 of 4					
6A – 9A	Shoulder Blockage	1				
	1 of 4					
	2 of 4			1		
	3 of 4					
	4 of 4				1	
9A – 3P	Shoulder Blockage	1	3	1		
	1 of 4				1	
	2 of 4					
	3 of 4					
	4 of 4					
3P – 7P	Shoulder Blockage	2	1	2		1
	1 of 4		1			
	2 of 4		1			
	3 of 4					
	4 of 4					
7P – 12A	Shoulder Blockage					
	1 of 4		2			
	2 of 4					
	3 of 4					
	4 of 4					

Table C-6. 2004 Incidents I-45 Southbound Cypresswood to Beltway 8.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage			4	1	1
	1 of 4	1				
	2 of 4		1	2		
	3 of 4					
	4 of 4					
6A – 9A	Shoulder Blockage	3	3	4	2	
	1 of 4	4	3	1	1	
	2 of 4	1		1		
	3 of 4					
	4 of 4				1	
9A – 3P	Shoulder Blockage	3	5	1		1
	1 of 4	5	1		2	
	2 of 4	1	1	2	1	
	3 of 4			1		1
	4 of 4			1		
3P – 7P	Shoulder Blockage	5	2	2	2	
	1 of 4	3	2	2		
	2 of 4	1	4			
	3 of 4	2	1			
	4 of 4					
7P – 12A	Shoulder Blockage	4	1			1
	1 of 4					
	2 of 4	1	3			
	3 of 4					
	4 of 4					

Table C-7. 2004 Incidents I-45 Southbound Beltway 8 to North Shepard.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage	3	1	1	1	
	1 of 4		1			
	2 of 4	1				
	3 of 4	1				
	4 of 4					
6A – 9A	Shoulder Blockage	3	5	1	2	
	1 of 4	4	3	4		1
	2 of 4		1	1		
	3 of 4					
	4 of 4					
9A – 3P	Shoulder Blockage	3	5	1	3	
	1 of 4	4	1	1		
	2 of 4			1	1	
	3 of 4					
	4 of 4					
3P – 7P	Shoulder Blockage	7	2	10	2	1
	1 of 4		2	2	2	
	2 of 4	1	1	3	1	
	3 of 4	1				
	4 of 4					
7P – 12A	Shoulder Blockage	1	1			1
	1 of 4		1	2		
	2 of 4	1		1		
	3 of 4		1			
	4 of 4					

Table C-8. 2004 Incidents I-45 Southbound North Shepard to I-610.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage	6	7	2		
	1 of 4	1	3			
	2 of 4	5	3	1		
	3 of 4	4	2			
	4 of 4					
6A – 9A	Shoulder Blockage	10	7	2	1	1
	1 of 4	13	9	4		
	2 of 4	5	5	1		1
	3 of 4					
	4 of 4					
9A – 3P	Shoulder Blockage	13	8	13	2	2
	1 of 4	12	6	4	5	
	2 of 4	3	8	4		1
	3 of 4	1	1	1		
	4 of 4					
3P – 7P	Shoulder Blockage	7	5	4	1	
	1 of 4	8	5	4	3	
	2 of 4	5	3	2		
	3 of 4					
	4 of 4		1			
7P – 12A	Shoulder Blockage	5	5	6	2	2
	1 of 4	8	4	2	1	
	2 of 4	3	2	3	1	
	3 of 4	1	2	2		
	4 of 4					

Table C-9. 2004 Incidents I-45 Southbound I-610 to I-10.

Time Period	Effect on Capacity (Number of Lanes Closed)	Duration of Incident (Minutes)				
		15	30	60	120	> 120
12A – 6A	Shoulder Blockage	5	4	2		
	1 of 4	3	2			
	2 of 4		1			
	3 of 4				1	
	4 of 4					
6A – 9A	Shoulder Blockage	3	2	1		
	1 of 4	5	6	3		
	2 of 4	1	3	2		
	3 of 4					
	4 of 4					
9A – 3P	Shoulder Blockage	2	4	3	1	1
	1 of 4	11	5	3	2	1
	2 of 4	3	4	3		
	3 of 4			2	1	
	4 of 4					
3P – 7P	Shoulder Blockage	2	2	3	1	
	1 of 4	5	2			
	2 of 4		1	2		
	3 of 4			1		
	4 of 4					
7P – 12A	Shoulder Blockage	2	4	2	1	
	1 of 4	1	1	2		
	2 of 4	5			1	
	3 of 4		1	2		
	4 of 4					

APPENDIX D

GUIDELINES FOR DYNAMIC MESSAGE SIGN PERFORMANCE EVALUATION

ABSTRACT

This guidebook is a result of research conducted under Project 0-4772, "Methods and Guidelines for Evaluating Dynamic Message Sign Performance," sponsored by the Texas Department of Transportation (TxDOT). It has been produced as a document to provide guidance to agency staff responsible for evaluation of the performance of dynamic message signs (DMS). Guidelines included herein discuss the requirements and availability of assessment data, measures of effectiveness for DMS evaluation, qualitative and quantitative benefits of DMS, steps necessary in a DMS evaluation plan, potential DMS analysis tools, and DMS evaluation limitations and constraints.

DISCLAIMER

The guidelines contained in this handbook have been taken from Research Report 0-4772-1, entitled *Guidelines for the Evaluation of Dynamic Message Sign Performance.* The contents of this handbook reflect the views of the research report authors, who are responsible for the recommended methodology and guidelines presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), Federal Highway Administration (FHWA), The Texas A&M University System, or the Texas Transportation Institute (TTI). This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof.

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BACKGROUND

Dynamic message signs (DMSs), also referred to as changeable message signs (CMSs) and variable message signs (VMSs), have been utilized for almost 40 years to communicate traffic information to motorists. DMS systems are an essential element of many advanced traveler information and traffic management systems and a primary component of intelligent transportation systems (ITS) architecture. While the majority of DMS deployment and application have been in urban areas, the last 10 years have seen extensive implementation in rural roadway environments as well. DMSs allow for the dissemination of real-time traffic information to motorists. In urban areas, DMSs are typically used to inform motorists of traffic conditions to be encountered (i.e., expected delays, estimated travel times, diversion routes, and lane closures) and have become an increasingly important source of motorist information during incidents, special events, and work zone traffic control. In rural areas, the focus of DMS utilization has been on displaying timely roadway and environmental condition information to enhance motorist safety.

The value of DMS systems, or any medium to communicate traffic information, is dependent upon ensuring that multiple criteria are satisfied, including:

1. The information disseminated is viable, reliable, and timely.
2. The messages conveying the information are legible, readable, appropriately placed, and comprehended by motorists.
3. Motorists believe the information provided to be credible and useful, are willing and able to respond to it, and do, in fact, respond appropriately to the information provided.

To the extent that a DMS system is deficient in meeting any of these conditions, the merit of the system will be compromised and potential advantages diminished.

Despite the significant progress realized in recent years with regard to DMS design and deployment, a critical issue that has received less attention and about which much less is known is the actual influence of DMS systems either during periods of congestion or incidents, or under normal traffic conditions. If DMS systems cannot be shown to have measurable effects on traffic conditions and/or public perception of those conditions, the value of even the best designed systems will be subject to question.

OBJECTIVE

The objective of Research Project 0-4772, "Methods and Guidelines for Evaluating Dynamic Message Sign Performance," was to provide TxDOT with objective guidelines and a methodological framework for evaluating DMS performance. These guidelines include a range of application locations (urban-rural), traffic flow conditions (incident-normal), level of assessment (quantitative-qualitative), time period of analysis (before-after), and availability of data to address all contingency scenarios. These guidelines are to allow TxDOT engineers to assess the effectiveness of existing DMS systems and to validate the implementation and efficient operation of systems. This guidebook was written and produced as a stand-alone document, included in Appendix D in final Report 0-4772-1, to be disseminated through the TxDOT Annual Short Course, the Traffic Management Section of the Traffic Operations Division, the Annual Meeting of the Intelligent Transportation Systems Texas Chapter, and other mechanisms.

SCOPE

The application of DMSs for communication of motorist advisory information may be classified into four broad categories:

- 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 (included here is the operation of directional lanes, tunnels, bridges, tollbooths and weigh stations, etc.).

Because DMSs have numerous applications and benefits, it is necessary to consider the goals of a particular DMS before evaluating its performance. Benefits will vary depending upon the intended use of the DMS, its location (e.g., urban verses rural), and its period of use. Benefits achieved by DMSs, including improved safety, time savings, increased throughput, cost savings, reduced emissions, and reduced fuel consumption, can be quantified to determine the effectiveness of the DMS. It is also necessary to consider qualitative measures, such as customer satisfaction, when evaluating DMSs. Consideration of the variables above can be used both to establish a framework for evaluation of DMS systems and to evaluate the benefits of individual DMSs in multiple settings.

MEASURES OF EFFECTIVENESS

Evaluating DMSs requires unique considerations not typically necessary in other transportation improvement projects. DMSs are intended to reduce delays and risks associated with incidents or unique conditions. Because incidents occur randomly, measures focusing on peak-period needs are not well suited for DMS evaluation. It is preferable to use measures that consider the impact of the incident and other unique operational conditions. Additionally, motorist response to DMSs is necessary to implement an effective system. Thus, consideration of motorist reactions to DMSs is essential in creating performance measures. These qualitative measures are sometimes difficult to compare but are just as imperative as other more quantitative indicators. The Federal Highway Administration has established a list of measures of effectiveness (MOEs) or performance metrics applicable to evaluation of ITS architecture which are "acceptable, understandable, and easily measured." These measures are as follows:

- crashes (fatalities and severe injuries),
- travel time (delays and queue length),
- throughput (volume and congestion),
- user satisfaction and acceptance, and
- cost.

Table D-1 shows performance indicators (MOEs) defined expressly for DMS evaluation.

Table D-1. Example Performance Indicators for DMSs.

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

* Tarry, S.A. Framework for Assessing the Benefits of ITS. *Traffic Technology International*, Aug./Sept. 1996, pp. 25-30.

ASSESSMENT OF DMS BENEFITS

Benefits through the implementation and effective performance of DMSs are manifested in several different forms. These varying types of benefits from DMS utilization must be assessed and compiled to establish the absolute and relative value of DMSs in terms of mobility, safety, and user satisfaction.

Benefits achieved through the implementation of DMSs have been quantified in several ways. These benefits must be analyzed to determine the effectiveness of a DMS. There are three common methods for analyzing any ITS improvement, including DMSs. These include benefit-cost analysis, impact analysis, and cost-effectiveness analysis. The most common of these methods is benefit-cost analysis. This method weighs the costs of a project to the benefits achieved. In this manner, desired projects yield the greatest net social-economic benefit. Cost-effectiveness analysis does not determine the net social benefit but compares projects based on their cost-efficiency. Finally, impact analysis focuses entirely on benefits of the project with no regard to the costs. A limiting factor of these approaches is the need for quantitative data for analysis. Any qualitative benefits achieved through the DMS cannot be included in these analyses. As stated previously, public acceptance of DMSs is very important for success, but this qualitative measure is very difficult to assess within the limiting factor, being assignment of qualitative value.

For operational purposes, preferably, both pre-installation and post-installation data are assimilated to allow comparative assessment of DMS implementation effects through benefit analysis. However, realistically, many DMS installations were incorporated in conjunction with other construction projects without forethought to obtain pre-installation quantitative or qualitative data. Many times, for these locations, only crash history can be obtained to assess pre- versus post-installation safety benefits. Therefore, whether for planning or operational purposes, time of assessment (i.e., pre- or post-installation) is a critical factor limiting the extent of DMS performance evaluation with benefit analysis.

The focus and extended potential of any benefit analysis for DMS performance evaluations depend also upon the environment of implementation, either urban or rural. Resources, equipment, and capabilities for data collection and directed benefits vary between a DMS implementation along an urban route or corridor versus a rural roadway. Application of DMS communication in urban highway environments emphasizes primary utility for sustainable mobility. Communications center on incident notifications to allow diversion for delay reduction. Monitoring of operations and traffic management strategies is much more sophisticated than in rural highway environments. Applications of DMS systems in rural highway environments do not necessarily address congestion issues but are instituted to improve safety through warning communications of adverse weather, incidents, or construction.

Public acceptance and satisfaction with DMS operations are critical qualitative benefit measures. The location of DMSs and the message display format must be perceived as acceptable from the standpoint of sufficient visibility, legibility, and presentation to allow an appropriate and timely response. Messages displayed must satisfy motorists’ expectations and needs for information that is useful/meaningful, accurate, reliable, and timely for the indicated advisement. Fulfillment of these information requirements with DMSs will optimize performance by influencing driver decisions and affecting behavior and response.

The actual driver responses to displayed DMS real-time information may be measured quantitatively to assess both mobility and safety benefits. DMS performance as a result of timely and appropriate driver responses may improve mobility on a roadway or corridor by reducing delay as measured by shorter queues, less average delay per vehicle, shorter travel times for a given trip length, and reduced total vehicle delay. Effective DMS performance will influence or generate motorist diversion from an impacted roadway, thus reducing vehicle demands for available capacity and distributing traffic on alternate routes.

Mobility benefits of effective DMS performance may also be quantitatively established through higher measured travel speeds and increased facility throughput at bottlenecks to improve level of service (LOS). Efficient DMS communication can improve overall traffic flow and maintain beneficial volume-to-capacity (V/C) ratios. Time of incident-related capacity restrictions can also be minimized.

Along with mobility benefits, or as an independent quantitative measure, safety may be improved through positive DMS performance. Displayed advisories of incidents, road conditions, work zones, or adverse environments ahead that are designed to promote increased caution or to induce speed or travel path adjustments may prevent or reduce traffic crashes or the severity of collisions. Crashes that do occur may be less severe due to slower vehicle approach speeds or avoidance maneuvers made as a consequence of responses to properly located and timely DMS-displayed information. Significant crash cost savings may be attributed to the reduction in crashes (positive safety benefits) resulting from DMS performance relative to that when no real-time motorist communication is available.

Figure D-1 provides a summary framework of potential DMS performance metrics utilized in the evaluation of benefits attributable to DMS installation. These performance metrics are segregated by the type of data employed in the analysis—quantitative or qualitative.

Depending upon time of assessment, pre- (before) or post- (after) DMS implementation, and/or the environment of DMS installation, urban or rural, any or all of these performance metrics may be used to analyze benefits.

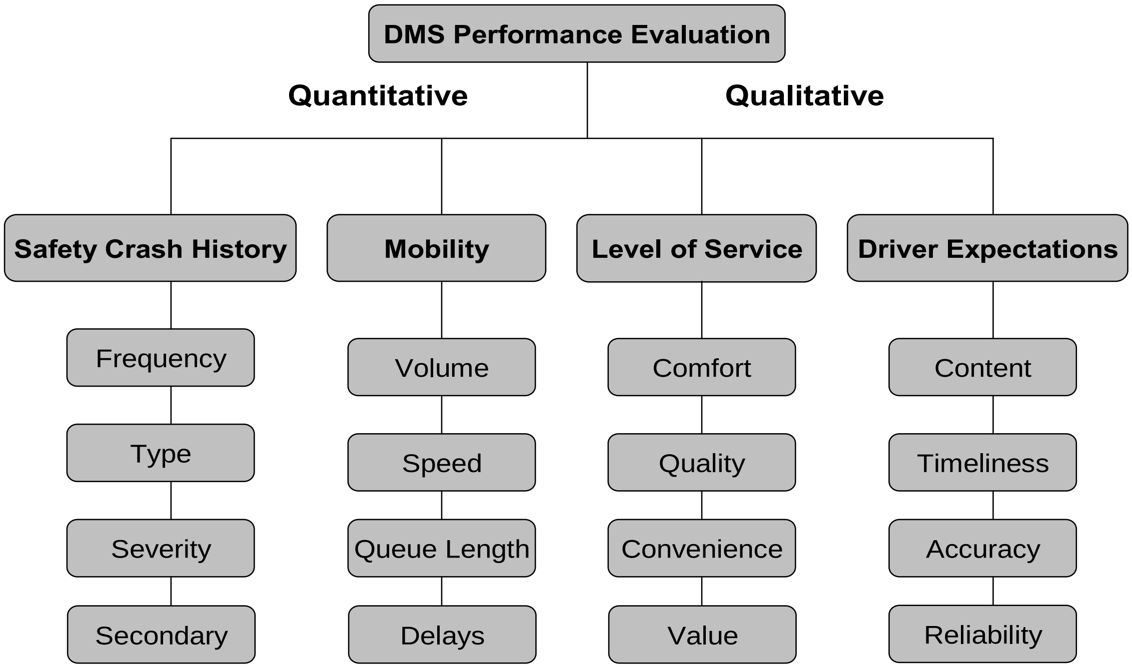


Figure D-1. Summary of DMS Performance Metrics.

Figures D-2 and D-3 illustrate both quantitative and qualitative DMS benefits as distributed between safety and mobility as well as differences between urban and rural environments of installation. Performance metrics used in analyzing benefits are categorized into groups on these graphs as each influences driver decisions for diversion.

GUIDELINES FOR DMS PERFORMANCE EVALUATION

Various types of benefit analyses may be employed for evaluation of DMS performance. The selection or application of a given analysis technique depends upon the availability of time and manpower resources for collection of required analysis data, the functional time frame of analysis, either in planning or operational phases (pre-post/before-after), and on the environment of DMS implementation, either urban or rural.

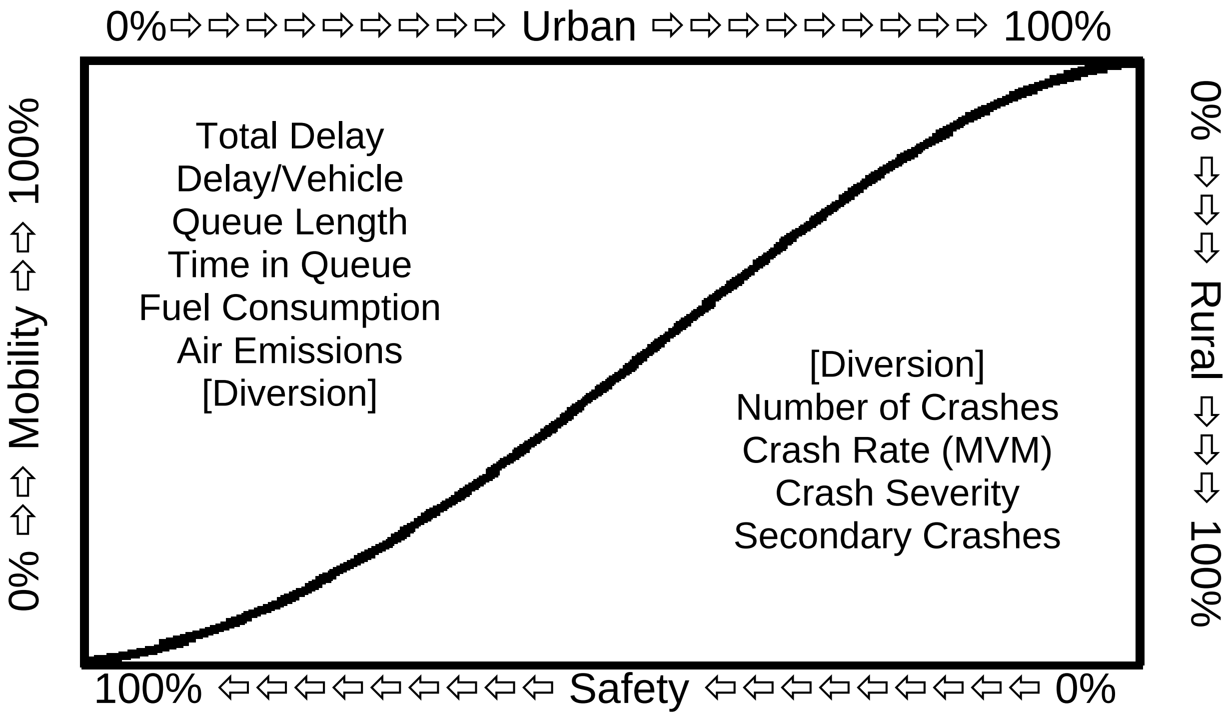


Figure D-2. DMS Benefits—Quantitative.

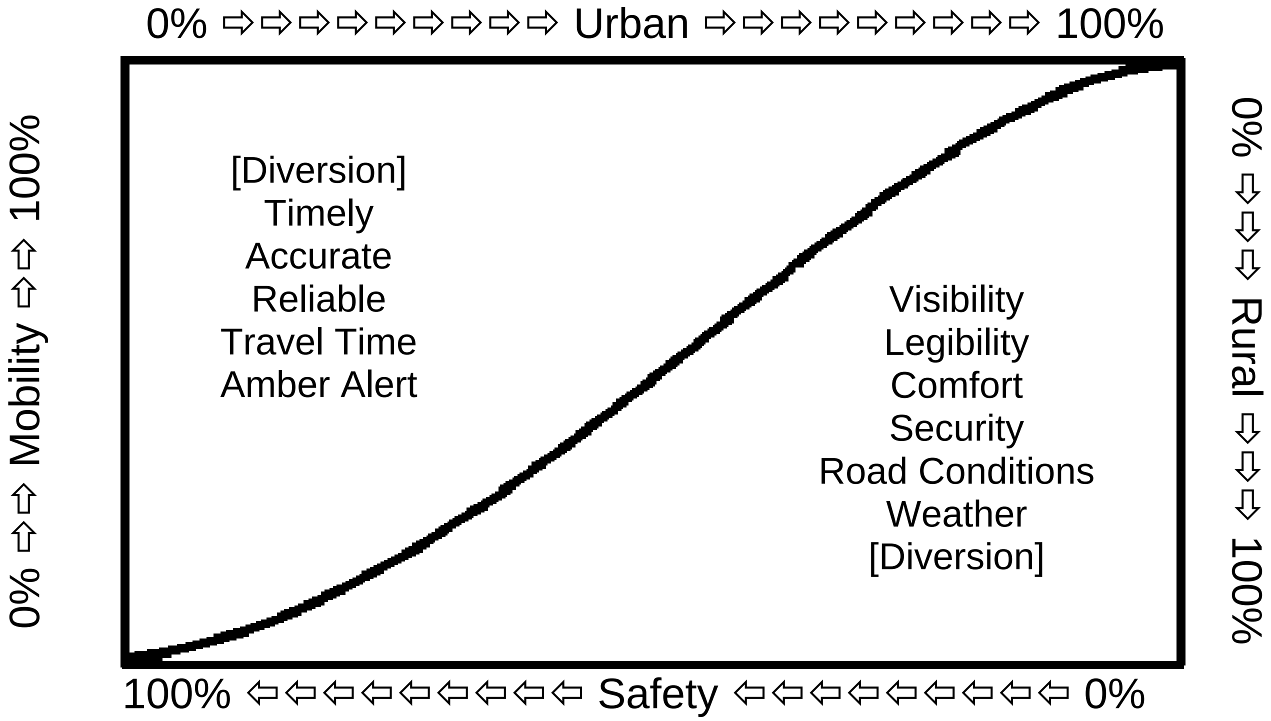


Figure D-3. DMS Benefits—Qualitative.

Benefit analysis applied in planning, or before DMS installation, may be used for several purposes: first, to establish baseline data conditions, using either qualitative or quantitative data, for subsequent post-implementation comparisons; second, to assess potential DMS benefits in justification of investment expenditures; and third, to optimize the location of DMSs along a route or corridor based on maximizing benefits. Benefit analysis used in planning to optimize DMS locations follows two methods—genetic algorithms and integer programming, i.e., simulation modeling, which has extensive data requirements that limit their application. It is important to note that the application of this methodology requires knowledge of the origin-destination trip matrix on a freeway, the characteristics of the freeway incidents, and an expected diversion response rate to DMSs located at decision points.

For operational purposes, preferably, both pre-installation and post-installation data are assimilated to allow comparative assessment of DMS implementation effects through benefit analysis. However, realistically, many DMS installations were incorporated in conjunction with other construction projects without forethought to obtain pre-installation quantitative or qualitative data. Many times, for these locations, only crash history can be obtained to assess pre- versus post-installation safety benefits. Therefore, whether for planning or operational purposes, time of assessment (i.e., pre- or post-installation) is a critical factor limiting the extent of DMS performance evaluation with benefit analysis.

The focus and extended potential of any benefit analysis for DMS performance evaluations depend also upon the environment of implementation, either urban or rural. Resources, equipment, and capabilities for data collection and directed benefits vary between a DMS implementation along an urban route or corridor versus a rural roadway. Application of DMS communication in urban highway environments emphasizes primary utility for sustainable mobility. Communications center on incident notifications to allow diversion for delay reduction. Monitoring of operations and traffic management strategies is much more sophisticated than in rural highway environments. Applications of DMS systems in rural highway environments do not necessarily address congestion issues but are instituted to improve safety through warning communications of adverse weather, incidents, or construction.

Developing “matched” pre- and post-DMS installation data for mobility benefit analyses is much more difficult. From a mobility assessment standpoint, it would be desirable to quantify volumes, speed, delay, queue lengths, and diversion along a potential roadway under consideration for DMS implementation. Such pre-installation documentation of both recurring and incident operations would allow comparisons to post-installation operations with DMS communications to establish mobility benefits from reduced delay.

In reality, most rural districts do not have the resources (detection equipment) in place to collect these data in either a before- or after-implementation condition. Some anecdotal information may be available or possible to produce from known incidents. However, unless recognized and accounted for early in the planning for a rural DMS system corridor, the capacity to collect the necessary data to establish mobility benefits does not exist.

Even in urban districts, which have the technology capabilities to measure the stated traffic operational parameters, many DMS installations were implemented randomly by site location or route as addenda to freeway reconstruction or rehabilitation projects. Because signs were installed but left blank for extended periods, signs were made operational but experienced major maintenance problems for extended periods, and/or signs were made operational under designated operational formats that changed significantly over time. True matched before-after comparisons are difficult to conduct.

Conceptually, situations where the DMS is used relatively infrequently (i.e., in rural environments primarily for weather-related advisories) require fairly simple and straightforward analyses although data availability may be a primary limitation. Conversely, urban environments where the DMS may be used almost continuously for an incident, roadwork (current and advance notification), special events, weather advisories, and other situations require a more systematic approach to the evaluation process. In high-use locations, a screening process must be employed to identify a finite number of scenarios that can be analyzed with the time and funding resources available. Obviously, the desire is to focus the analyses on those application scenarios that likely yield the most substantial changes in traffic performance.

The methodology for estimating the safety and mobility benefits achieved through the installation and operation of DMSs consists of four main steps:

- identifying and prioritizing DMS application scenarios for evaluation,
- developing the evaluation plan tailored to DMS applications of interest,
- conducting the evaluation, and
- performing and interpreting the evaluation results.

The first two steps ultimately define both the time and costs of the evaluation that will be required (they will also likely dictate how accurately the DMS performance is evaluated). The first step of a DMS analysis is to characterize how the sign or system of signs is used (in the case of a planning evaluation, how they are to be used). This characterization includes the following:

- the types of applications for which the signs are used (incidents, roadwork activities, special events, adverse weather/pavement condition warnings, etc.);
- the relative frequency of their use by type of application, time of day, problem location, direction of travel, and impact upon roadway capacity, if applicable; and
- duration of use per usage.

Historical records of device utilization and/or incident logs are the most logical sources of information upon which to base this characterization. Depending on the amount of data available and frequency of use, the characterization process can be based on average conditions or on relative distributions across one or more of the parameters. For instance, Table D-2 illustrates a hypothetical characterization of DMS use in a freeway corridor where distributions by time of day, effect on roadway capacity, and durations of use are all estimated. Once DMS usage is characterized in this fashion, the analyst can assess these values to determine which scenarios are expected to result in the most substantial changes in traffic performance and which are likely to yield only minimal changes in driver behavior and, thus, whose effects will be more difficult to capture. Those scenarios expected to not contribute significantly to the overall summation of DMS impacts can be eliminated as a means of establishing a manageable evaluation plan. Once DMS utilization has been characterized and prioritized, the next step is to identify and develop the evaluation plan that provides the best estimate of expected driver responses to each of the types of applications that have been identified for the DMS of interest.

Table D-2. Hypothetical Example of Reducing and Consolidating DMS Use.

Type of Application	**No./ week**	**%**	**Time of Day**	**%**	**Effect on Capacity (Lanes Open/Closed)**	**%**	**Duration (%)**			
							15	**30**	**60**	**120**
Incident Notifications	60	75	AM Peak (6 am – 9 am)	30	3/0 (shoulder)	40	20	50	25	5
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	5	15	30	45	10
			Daytime Off Peak (9 am – 4 pm)	20	3/0 (shoulder)	▨	▨	▨	▨	▨
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	▨	▨	▨	▨	▨
			PM Peak (4 pm – 7 pm)	40	3/0 (shoulder)	40	45	▨	50	5
					2/1	35	55	▨	40	5
					1/2	20	45	▨	45	10
					0/3 (full closure)	5	30	▨	60	10
			Nighttime Off Peak (7 pm – 6 am)	10	3/0 (shoulder)	▨	▨	▨	▨	▨
					2/1	35	30	45	20	5
					1/2	20	20	45	25	10
					0/3 (full closure)	▨	▨	▨	75	25
Roadwork Notifications	4	3	Daytime Off Peak (9 am – 4 pm)	100	2/1	75	▨	▨	▨	100
					1/2	25	▨	▨	▨	100
Etc.			Etc.							

* Cells shaded will not be assessed in the evaluation.

Driver responses that can be quantified and eventually equated to a dollar figure (a key goal of this project) are limited to either safety benefits (reduction in crashes) or mobility benefits (reductions in delay and stops).

Benefits in safety via DMS use are believed to be achieved by increasing awareness and preparing motorists for downstream hazards (presence of queues or closed travel lanes, degraded visibility or pavement conditions, etc.) such that motorists are better prepared for the conditions they are about to encounter and are less likely to cause or be involved in a mishap themselves. While operational surrogate measures of safety are sometimes used for evaluation purposes (i.e., measuring differences in speeds approaching the back of a traffic queue), the connection between these measures and true safety improvements is typically not defined at all or is based on very weak correlations.

Benefits in mobility can be achieved either through improved traffic flow through the system (less turbulence) that results in higher capacities, or by effecting a redistribution of traffic through diversion that reduces traffic demands at a bottleneck and, thus, reduces congestion and delays. The reduction in delay is then converted to an equivalent dollar savings by multiplying a value of time by the delay reduction. Any savings in fuel consumption that occurs due to the traffic redistribution process can also be converted to an equivalent dollar amount as well and added to the delay savings. This reduction in delay is offset somewhat by the longer travel distances that may be required of those choosing to divert. The ability of the analysis to account for travel distance increases depends on the size of the roadway network considered in the evaluation.

Although in theory both types of benefits could be achieved through many of the DMS applications that are possible, it will typically be very difficult to assess safety improvements in high-volume urban corridors that are solely due to the presence of DMSs. This is because the traffic surveillance infrastructure necessary to support DMS operations will also most likely be used to enhance commercial radio reports, Internet websites, reduced incident durations, etc., all of which may also improve safety in the corridor.

At the same time, it may also be difficult to assess any mobility benefits due to DMS use in a rural application, where the signs are installed primarily to provide adverse weather and pavement condition information. In these situations, a lack of feasible alternative routes and even the lack of accurate traffic volume and speed data along the roadway corridor may all conspire to limit consideration of DMS benefits to safety improvements.

Other difficulties are manifest in measuring true mobility benefit indicators that can be fiscally accounted for. For example, queue lengths can be correlated with vehicle delay and valued, but unless all traffic volume is measured in and out of a given incident queue over time, a complete assessment cannot be made. In an analysis of input-output volumes along a facility with DMS communication, it is difficult to establish the differences in approach volumes that are the result of DMS influence as opposed to other factors that cannot be accounted for, i.e., lower traffic due to public radio advisories, etc.

A before-after safety benefit analysis utilized for DMS performance evaluation involves a comparison of vehicle crashes along a roadway or within a highway corridor prior to the installation of a DMS system for real-time motorist communication to those crashes experienced on the same facility after DMS system installation. Conceivably, more effective, timely advisement of weather changes, pavement conditions, construction, and/or incidents will allow motorists to heighten attention and alertness, exercise increased caution, adjust driving behavior, and avoid or reduce the number and severity of crashes.

This crash comparison should desirably be made within a minimum of 3 years of pre-post installation crashes. Crashes of significance for comparison are those defined as “preventable” or “susceptible to correction” that have no adverse driver behavior involved, i.e., alcohol, excessive speed, reckless driving, no license, etc.

Before-after DMS installation comparisons should include not only total crash frequency for a given roadway section length (miles), but also incorporate vehicle miles traveled (VMT) for the period of analysis, thus allowing calculation of crash rates. This will allow an assessment of safety relative to other similar functionally classified facilities. The roadway length used for evaluation purposes should extend from just upstream of the first DMS in the segment that is being evaluated to beyond the expected limits of the DMS's influence in the corridor (dependent upon the entering and exiting travel patterns of the travelers on that roadway segment). On freeway facilities in rural areas where most of the traffic is long-distance travelers, the influence area may be 10 or 20 miles in length. Urban areas, on the other hand, may have potential influence lengths of only a few miles.

As noted, at least 3 years of crash data prior to the implementation of the DMS should be used to establish the "before" crash trends as a way of reducing any regression-to-the mean effects that may be present. If possible, comparison sections of similar geometric and traffic characteristics, but without the influence of DMS installations, should also be selected to account for any external changes (i.e., increased traffic volumes, highly different weather patterns, etc.) that might also influence crash frequencies and types in the region. If such a comparison segment is not available, then an adjustment for changes in traffic volumes over time along the roadway segment being evaluated must be made. Over a multi-year period of analysis, a roadway or corridor where a DMS system has been deployed may experience growth in traffic volume. In that, some portion of vehicular collisions are directly proportional to traffic volume due to probability of conflicts; increases in traffic volume influencing crashes must be accounted for and appropriate adjustments made to the after DMS installation crash experience. This adjustment to after crashes due to traffic growth is made with the following calculation:

$$\text{Reduction \%} = \frac{\text{After Volume (ADT)} - \text{Before Volume (ADT)}}{\text{Before Volume (ADT)}}$$

After DMS installation crashes are reduced by this calculated traffic growth percentage to allow a "normalized" comparison of effect.

The specific crash types that should be examined and compared at a given location between the before and after time periods will depend on the actual DMS application types (and corresponding driver responses anticipated) that were selected for evaluation. In urban areas, for example, safety benefits may be expected through DMS use by warning motorists of downstream congestion caused by earlier incidents (i.e., reductions in secondary crashes) and by encouraging safer driving during adverse weather/pavement conditions. In this case, the analysis should be directed toward assessing both secondary crashes and adverse weather conditions primarily. In rural areas, it may be only the adverse weather events that are of interest to the analysis, if volumes are such that other types of incidents where secondary crashes could occur do not occur with any regularity.

Ideally, the crash analysis should include multiple years of after data since regression-to-the-mean effects may also arise during this time too. In reality, the after period may be limited to only 1 year's worth of data, or even less than a full year. If the latter condition occurs, the comparison to the before data should be based on comparable months (i.e., use only part of each year of before data that matches the after period data that are available). A reduction in crashes along a route or corridor where DMSs have been deployed may or may not have been the result of effective DMS performance. The comparison of before DMS installation crashes to after DMS installation crashes must be tested for statistical significance to establish at a given confidence level (95 percent) if the measured reduction occurred by change probability or the result of DMS influence.

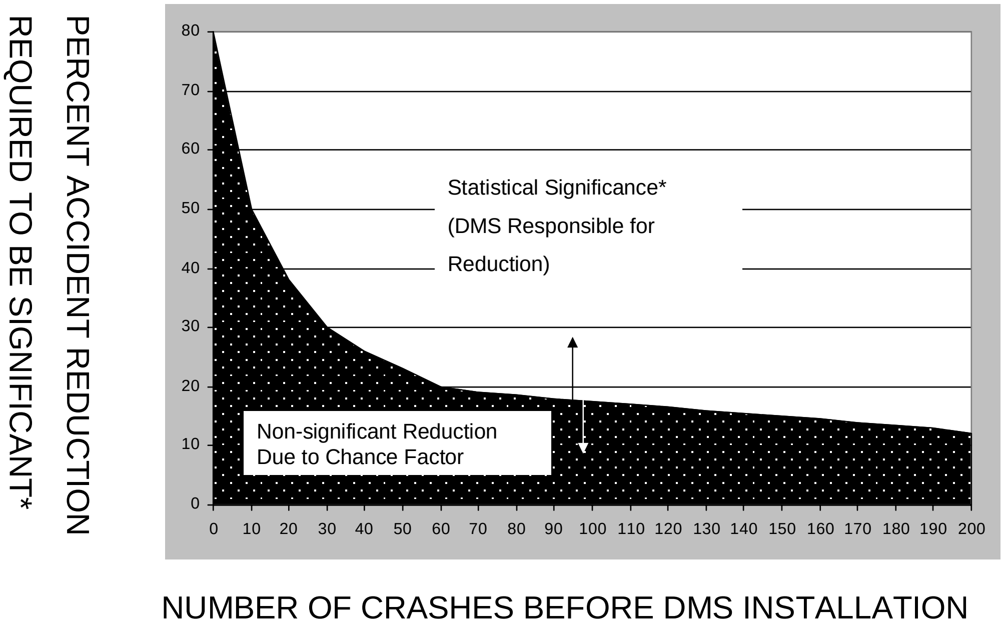
If a suitable comparison section has been identified, the calculation of the change in crashes (in total or for each of the subcategories of interest) is computed as a simple cross-product ratio:

$$\%\text{ change} = \left[\frac{(\#\text{ of Before Crashes}_{\text{comparison}})(\#\text{ of After Crashes}_{\text{DMS section}})}{(\#\text{ of After Crashes}_{\text{comparison}})(\#\text{ of Before Crashes}_{\text{DMS section}})} - 1\right] \text{x } 100\%$$

The change can be assessed statistically by transforming the ratio into a standard normal statistic:

$$Z = \frac{\ln\left(\frac{(\#\text{ of Before Crashes}_{\text{comparison}})(\#\text{ of After Crashes}_{\text{DMS section}})}{(\#\text{ of After Crashes}_{\text{comparison}})(\#\text{ of Before Crashes}_{\text{DMS section}})}\right)}{\sqrt{\frac{1}{(\#\text{ of Before Crashes}_{\text{comparison}})} + \frac{1}{(\#\text{ of Before Crashes}_{\text{DMS section}})} + \frac{1}{(\#\text{ of After Crashes}_{\text{comparison}})} + \frac{1}{(\#\text{ of After Crashes}_{\text{DMS section}})}}}$$

Figure D-4 illustrates a simple chi-square test for statistical significance of before-after crash reduction under DMS deployment if a comparison section is not used.



*At 95% Confidence Level

Figure D-4. Chi-Square Example.

Regardless of the analysis approach selected, costs must be associated with each individual type of crash that is estimated to have been reduced through the implementation and utilization of DMSs in the corridor. These costs may be referenced from the National Safety Council (NSC) and are given for 2004 as follows:

- fatal (K)—$3,760,000;
- type A—$188,000;
- type B—$48,200; and
- type C—$22,900.

The effectiveness of DMSs in improving mobility would ideally be evaluated on the basis of historical data collected before and after DMS deployment. Unfortunately, the operational MOEs of interest that can be converted into economic value travel time and delay are difficult to measure in the field at the level of accuracy needed for comparison evaluation. Other MOEs such as fuel consumption and environmental MOEs (e.g., vehicle emissions) are not measurable directly in the field under any circumstances. The detection systems (e.g., loop detectors, sensors, or video detection) required for the continuous monitoring of these data are commonly installed in connection with the deployment of DMSs and traffic management centers (TMC). They are either missing or very limited prior to DMS deployment at most locations. Therefore, the *"before"* data that would be required to establish a baseline, or frame of reference, for DMS evaluations are often not available. The situation is just the opposite for future system installations. In such cases, the *"after"* data are not available, and therefore, only expected system benefits can be predicted.

Traffic simulation models can play an important role in DMS evaluations. They can also be used to evaluate the performance of existing DMS systems and predict the expected benefits of future DMS installations. The primary advantage of using traffic simulation is that the expected operational benefit of a DMS can be estimated for any combination of traffic, roadway conditions, and incident situations that are rarely encountered, which are, therefore, very difficult to observe in the field. At locations where the detectors and sensors required to collect system-wide before and after study data for evaluating DMS effectiveness are missing, a properly calibrated traffic simulation model may be the only means of reliably estimating the effect of DMS messages on traffic operations on the entire freeway arterial network. Also, the run time required for simulating multiple scenarios (e.g., combinations of different traffic demands, incident durations, and variations in traffic control strategies) is much shorter than the time required for the field observation of a single event.

The evaluation plan to estimate the mobility benefits of DMS implementation includes the following considerations:

- identifying the appropriate scope of the analysis (microscopic or macroscopic),
- identifying an appropriate analysis tool,
- determining data requirements,
- calibrating the tool to known conditions,
- determining incremental effect of DMSs upon driver responses,

- calculating changes in operational measures for each DMS application scenario of interest, and
- converting operational improvements into economic value.

The operational and environmental effects of a DMS message that encourages traffic diversion to an alternate route can be modeled using either a microscopic traffic simulation model (e.g., CORSIM, VISSIM, INTEGRATION, PARAMICS, or MITSIM) or a macroscopic model (less data intensive). However, evaluation of the effectiveness of a DMS message about future changes in traffic control is a more complex task because these advance information communications are typically disseminated through several other channels in addition to the DMS. The contribution of these different information sources to the entire system benefit is very difficult to estimate. Dynamic route-choice algorithms mimic the entire traveler information system effect, not just the incremental effects of the DMS. The extent to which the algorithms themselves even represent the combined effect of traveler information on driver behavior is a subject of debate at this time; therefore, factors other than the representation of dynamic route-choice behavior should be used to determine which tool is selected for use. Once the tool is selected, the analyst will need to be able to explicitly alter traffic volume inputs to represent the estimated effect of DMSs on route-choice behavior. This alteration of demand is corridor or region specific and computed based on estimates of diversion response or from stated preference surveys of motorists using that corridor (this process is described in greater detail below).

A specific type of survey has been increasingly used in recent years to predict and model driver behavior in relation to transportation facility improvements such as DMSs. Based largely in economic theory and marketing applications, a family of survey techniques, known as “stated preference,” has been developed wherein respondents are asked to choose between various options. These surveys offer a means for evaluating existing and planned DMS-equipped facilities in terms of the impact of specific DMS characteristics on the choices drivers make when confronted with a given DMS message at a particular location. The primary decision of interest here is the binary choice a driver makes to divert or not divert from his normal route. The same approach can be used to estimate significant changes in speed selection or other driving actions that depart from the norm. Stated preference surveys ask respondents how they would behave in specific, well-defined hypothetical situations. Stated preference surveys can be especially important for estimating the incremental effects of DMSs on driver responses, particularly when no or limited operational data relevant to diversion are available.

The results of stated preference surveys can be used directly to estimate the impacts of a DMS improvement, or in their more sophisticated application, as proposed here, surveys can be developed that can be used in conjunction with other data to support quantitative simulation models. The goal here is to provide valid and reliable estimates of the percentage of diverting traffic under multiple scenarios. An example of a sample scenario and hypothetical choice item included in a stated preference survey is given in Figure D-5.

Once the percentage of diverting traffic is determined, the diversion process itself can be modeled by either static or dynamic vehicle routing. Static routing assumes that the percentage of vehicles diverting in response to a DMS message is constant over time. In case of dynamic vehicle routing, the percentage of vehicles may change over time in response to downstream traffic conditions on the freeway and the alternate route. Calibration of the analysis tool to known conditions is a critical but often overlooked step in the use of traffic operations analysis tools. If the DMSs are already installed along the travel corridor, calibrating to conditions to all or at least some of the DMS application scenarios of evaluation interest is the preferred approach. Then, when the incremental changes in route choices due to DMS information are estimated via survey techniques described below, input traffic volumes can be adjusted accordingly to estimate the expected traffic conditions that would have resulted if the DMS had not been present.

The model output used in the calibration process depends on observation data availability. The two outputs that are most likely to have field data counterparts are link flows and average speeds. If travel times were recorded or estimated from speed data, they can also be compared to simulated travel times. Observations on queue sizes are also useful for model calibration. Most calibration parameters that may be adjusted in the models are related to either vehicle or driver characteristics. Typical driver behavioral parameters such as gap acceptance, car-following

Each of the following items asks you to choose among several possible options. Please indicate by placing an X in the appropriate box, the one option you would choose based on your current knowledge about driving on I-XX if you were faced with the specific conditions described and pictured below:

ITEM 1

It's 7:15 am, and you are on your drive to work.

You are driving alone northbound in the center freeway lane of Interstate XX.

You are four exits south of 5th Street where you usually leave the freeway.

The road is dry, and traffic appears to be about the same as usual.

On I-XX just prior to 9th Street, you see the following sign:

I-XX NORTH AT
7th STREET
MAJOR ACCIDENT

What would you do?

Place an X in the one box below that best indicates what you would do:

- ☐ Maintain my lane position and continue on I-XX to my usual exit at 5th Street.
- ☐ Move to the right lane and continue on I-XX to my usual exit.
- ☐ Exit the freeway at 9th Street exit.
- ☐ Exit the freeway at 8th Street exit.

Figure D-5. Sample Scenario and Hypothetical Choice Item.

sensitivity, and minimum headway may be adjusted to meet existing link capacities. Another important parameter is the maximum (emergency and non-emergency) deceleration that may be specified for different vehicle types. Since minimum headway is a function maximum deceleration, altering these rates gives the modeler some control over the density of the system. Other parameters related to lane-changing maneuvers are also important to calibrate the model, particularly when the network includes lane closures, exit and entry ramps, or weaving sections. Proper selection of the type of probability distribution (e.g., uniform, normal, or Erlang) for generating vehicles at entry points may also be important.

In summary, the data desired for the calibration of the simulation model are the following:

- volume data—traffic counts measured in selected points of the network;
- speed data—average speeds in selected points of the network;
- travel times—travel times measured on freeway and alternate routes;
- queuing—time when queues began forming, and time when traffic returned to normal condition; and
- queue size—length of maximum queue.

Traffic diversion determined from field observations or surveys is typically represented by a single number, a percentage of freeway traffic, which is considered constant for the entire time period when a warning message is displayed by a DMS. In such cases, whether the assumption of constant diversion is right or wrong, traffic diversion can only be simulated by diverting the same percentage of traffic regardless of downstream traffic conditions. Although it is unrealistic, this approach may produce reasonable estimates for some MOEs (e.g., overall throughput and average delay) in certain cases. If the simulation is used for the evaluation of an existing system, it is also an option to consider the percentage diversion as model parameter and fine-tune it during model calibration. However, in case of new DMS installations, the expected percentage of diverting traffic can only be determined from surveys, or field observations conducted at other DMS-equipped locations with similar traffic and roadway conditions.

Traffic diversion using static vehicle routing can be simulated using a number of microscopic traffic models, including CORSIM and VISSIM. As mentioned earlier, the degree of traffic diversion is not only a function of the warning message. It also depends on the actual traffic conditions on the freeway and the alternate route, the vehicle composition (i.e., truck percentage), driver composition (i.e., percentage of commuting and local traffic), and a number of other factors observed by the motorists as they approach the diversion point. Therefore, the percentage of diverting traffic is constantly changing over time, which can only be modeled by dynamic vehicle routing. In dynamic vehicle routing, the simulation model continuously updates the percentage of diverting vehicles by applying certain diversion logic specified by a set of if (*conditions*) then (*consequence*) type rules, or a route choice model. Several other variables such as average speed on the diversion routes or queue length on the freeway or the exit ramp may also be included as *conditions* in the rules. These rules would be generated from the results of the driver surveys that provided an indication of the sensitivities of diversion behavior in response to both DMS information and roadway conditions.

Using either the static or dynamic approach to diversion modeling, the MOEs (e.g., travel time, delay, stops, queue length, fuel consumption, and emission) required for evaluating the effectiveness of a DMS can be calculated for a range of traffic demands and incidents of different types and durations. A primary disadvantage with limited resources of performing an evaluation using microscopic simulation tools is the large amounts of data needed. For example, the following data are required for setting up a simulation model for evaluating DMS effectiveness:

- Geometric data—Number of lanes, lane widths, location of lane additions/drops, grades levels, and entry and exit ramp locations need to be specified for the entire network of interest.
- Speed data—The speed limits and/or free-flow speeds for roadway sections need to be analyzed.
- Volume Data—Traffic volume data are needed at each point where vehicles can enter the network.
- Incident data—These data come from the DMS application scenarios to be evaluated as defined previously, and they include the time of onset, duration, location and affected roadway length, and number of lanes closed.

- Traffic control—For network-level evaluations, stop or yield signs, signalized intersection phases, timing plans, detector locations, and lane configurations are needed.

Once all of the analyses are completed, a series of incremental changes in delay or travel time, fuel consumption, and possibly vehicle stops estimated to be the result of DMS implementation on a roadway segment will exist for each of the DMS application scenarios initially selected for analysis. These incremental changes are then multiplied by the frequency with which they occur in the corridor over the evaluation period of interest. If the intent is to establish a benefit-cost ratio for the DMS installation, then the analysis period would extend over the service life of the DMS equipment. If the intent is to compute the estimated benefits only, then the time period of most interest to the use (i.e., per month, per year, etc.) can be selected.

Once the total amount of vehicle delay reductions, fuel consumption reduction, and/or vehicle stop reductions due to the DMS installation have been summed over the analysis period of interest, each is multiplied by an appropriate economic value and summed to determine the total economic benefit of the sign(s). Although there are some variations in the value of traveler time assumed in analyses, past FHWA publications suggest values of $10 to $13 per vehicle-hour for automobiles and $17 to $24 per vehicle-hour for trucks (in 1996 dollars). Current fuel prices can be used to estimate fuel consumption benefits, and the same FHWA publications can be accessed to estimate the reduced vehicle operating costs (VOCs) achieved through fewer stops and idling time in queue.

Qualitative benefit analyses for DMS performance evaluation are directed to establishing DMS influence on driver decisions (and ultimately their quantifiable responses) and motorist opinions about the worth or value of DMS communications. These types of analyses obtain information through motorist behavioral studies that include collecting user information elicited from focus groups, or through conducting surveys, including attitudinal, opinion, and/or previously discussed stated preference approaches.

Another approach to qualitative benefit analysis is to obtain information from focus groups. It should be noted that the term “focus group” is short for “focus group interview.” To function best, planners of these groups need to attend to all three concepts. This technique, as contrasted with both other group processes and other interview approaches, should be limited to a small set of issues that can, in part because of its focused scope, be explored in some depth. As a group process, the focus group is directed toward encouraging interaction and discussion among its participants that have the potential for eliciting information that is more than a simple summation of individual participants' contributions. As an interview, the group is not a completely free-wheeling, undirected process. Rather, it is directed by a moderator whose job is to promote interaction and genuine discussion and to make certain that the group remains on the specific topics of interest while still providing an atmosphere conducive to an uninhibited and full exchange of views and information.

Questionnaire-based survey instruments, either self-administered or administered via telephone or in-person interviews, that are developed to elicit qualitative and quantitative data from users and potential users of facilities with existing or proposed DMSs can, if well designed and implemented, enhance or replace group interviews as a means for getting DMS evaluation information from drivers. Unlike focus groups, survey data can be used to make valid statistical statements and, with appropriate sampling and statistical procedures, can be generalized beyond the sample of respondents to the larger population.

Surveys used to support DMS evaluation can cover a broad range of issues and specific questions dealing with driver attitudes, familiarity with and knowledge about DMS issues and operations, and preferences for specific DMS attributes. They can be administered by mail, as household or business drop-off surveys, over the Internet as web-based surveys, or through telephone contact.

Within the context of DMS performance evaluation, a survey, usually some form of questionnaire instrument used for qualitative benefit analysis, can be developed to obtain a wealth of information, including:

- types of vehicle driven, e.g., passenger vehicle or commercial truck;
- driving experience, e.g., by age or number of years with valid driver license;
- frequency of driving on DMS route, e.g., daily, weekly, or monthly;

- experience with DMS systems, i.e., the extent to which DMSs have been viewed or utilized;
- understanding of DMS purpose, i.e., real-time motorist communication;
- expectations of displayed information, including content, display format, or location;
- satisfaction with DMS displays in terms of perceptions of content, format, timeliness, accuracy, reliability, usefulness, or criticality;
- importance of information currently or planned to be displayed, e.g., weather, pavement condition, construction, accident, special event, etc.;
- reported response to displayed DMS information, e.g., are they ignored, promote greater awareness/alertness, increase motorist caution, speed adjustment, diversion, etc.;
- detail of information displayed, e.g., delay, diversion, or incident location;
- factors influencing perceived DMS usefulness, e.g., timeliness, accuracy, or reliability;
- evaluation of operational performance, e.g., are DMSs perceived as adequate, inadequate, or in need of change;
- assessment of DMS benefits, in terms of utility, safety, or mobility; and
- opinions regarding DMS expenditure justifications.

Among the advantages of questionnaire-based surveys over focus groups or other interview methods are:

- Administration is less time consuming for individual respondents than focus groups.
- Surveys can be anonymous.
- Surveys can be more economical per respondent than group interviews.
- Survey results are much more amenable to generalization.

CONCLUSIONS

Based on the previous discussion, analysis, and lessons learned from the case study validation, DMS performance evaluation is primarily dependent upon three factors:

- environment of DMS application, i.e., urban or rural freeway corridor;
- availability of data necessary for evaluation; and
- limitation to resources available for evaluation, i.e., time and/or manpower.

The environment of application, whether urban or rural, dictates the possible benefits accrued and measurable from either delay reduction (enhanced mobility) or crash reduction (safety). The availability of data, before and/or after DMS application, allows or restricts the extent of evaluation. Also, resources within most responsible agencies are always limited. Therefore, the final evaluation methodology will focus on the most possible benefits to be accrued with reasonably expected evaluation data to be found in the two most common application environments of urban and rural under conditions of limited agency resources. Attention should be given to the previously discussed Figure D-1, which provides a summary framework of potential performance metrics utilized in the evaluation of benefits attributable to DMS installation. These performance metrics are segregated by type of data available for analysis and extent of analysis—either quantitative or qualitative.

Quantitative benefit analysis addresses direct measurements of DMS impact on both mobility and safety along a given route, network, or corridor of implementation. Comparisons are made between pre-installation and post-installation conditions to establish mobility and safety benefits demonstrated through congestion/delay and crash reductions and associated cost savings. Qualitative benefit analyses are directed to establishing DMS influence on driver decisions (and ultimately their quantifiable responses) and motorist opinions about the worth or value of DMS communications. These types of analyses obtain information through motorist behavioral studies that include collecting user panel trip diaries, collecting information elicited from focus groups, or conducting surveys, including attitudinal, opinion, and stated preference approaches.

Further delineations of the final DMS performance evaluation will be divided by the environment of application—urban or rural. Figures D-2 and D-3, previously shown, illustrate the relationship between DMS application environment (urban/rural), DMS benefits (quantitative/qualitative), and DMS performance metrics.

Urban DMS Methodology

Urban applications of DMSs are characterized by extensive deployment coupled with other ITS infrastructure throughout a given corridor or region. Typically, DMS systems in urban environments are heavily utilized for numerous types of motorist communications focusing on incident advisement, construction and maintenance activities, special event traffic management, and travel time (delay) information.

The value (benefits) of these DMS displays may be assessed qualitatively through opinion surveys that establish the utilization of DMS communication to fulfill driver expectations as to message content, timeliness, accuracy, and reliability. The construct of the motorist opinion survey may be as simple as that given in Figure 6 or as extensive as that given in Appendix A, which includes questions to assess the potential of driver response for diversion. Administration of the motorist opinion survey to assess DMS performance should be facilitated at a location in proximity to the DMS study route or corridor that will allow convenient and safe access to drivers exposed to the subject DMS installations such as a driver licensing station, truck stop, or shopping mall. Sample size may vary from 300 to 1000 participants, depending on time and manpower responses.

Quantitative benefits of DMS performance in urban applications may be established from reduction in traffic crashes or vehicular delay. The former, safety benefits, is difficult to assess in the primary crashes on urban freeways and predominately is a product of high volume or exposure. Those crashes, or reduction in crashes, potentially preventable due to DMS communications cannot necessarily be isolated from the many other variables that influence safety. Secondary crashes may possibly be isolated and identified; however, other aspects of an ITS deployment may be influencing any changes in these crashes as well (i.e., reduced incident durations) such that it may not be appropriate to attribute their reduction solely to the presence of DMSs. The latter, reduction in delay, may be established dependent upon available data relative to mobility such as entrance/exit/through volumes, speeds (travel time), and length of queues under various incident conditions by location and time of day. However, for a congested urban freeway, the magnitude of the data requirements in this regard is overwhelming unless planned for far in advance of DMS performance assessment. It has also been demonstrated that attempting to assess DMS performance with any type of microscopic network simulation model (VISSIM, CORSIM, etc.) is tedious to calibrate and cost prohibitive in terms of time and manpower to utilize in an urban freeway corridor.

A macroscopic analysis, such as that suggested previously incorporating a permeability factor to account for diversion influenced by motorist communications, can be performed to generate order of magnitude impacts. The key to this type of analysis is either the measured, estimated, or assumed diversion potential instituted from DMS incident information displays. The range of this diversion value remains unknown at this time, but an initial guess of a minimum of 5 percent to a maximum of 15 percent may be reasonable. It is expected that this percentage is regional, corridor, and site specific and should be determined explicitly through proper measurements of approach volumes immediately upstream of the traffic queue during the incident, and then at the same time of day without an incident to determine the difference that the DMS appears to have had on demand. Then, utilizing an algorithm such as the previously discussed "permeable pipe" model of macroscopic traffic flow, estimates of queue length and vehicle delay within a corridor can be computed through repeated additive calculations of various types of incidents by location, time period, duration, and lane closure. Incremental differences may be established between the normally expected incident volumes and incident volumes resulting from some percentage of DMS diversion. Applying current road user cost value ($13.50/vehicle-hour) to that summation of reduction in delay due to specified DMS diversion yields calculated mobility benefits for any particular site, section, or urban freeway corridor. It must be re-emphasized that although this macroscopic analysis procedure or methodology does allow a quantifiable estimate of delay reduction benefits resulting from DMS application in an urban freeway corridor, it is limited in scope to only response to incidents or other conditions that would reduce roadway capacity below demand and create traffic queues. These conditions may be a small subset of the total mobility benefits that actually accrue with DMS use.

Rural DMS Evaluation Methodology

In contrast to urban DMS applications, implementation of DMSs in rural freeway corridors is limited and more selective for motorist communication to use. The frequency of incidents requiring display of advisement and response information is much less. Congestion levels whereby demand volume exceeds capacity are rare, and in many corridors, diversion alternatives are limited. Speeds are higher, resulting in higher crash severities. In many instances, weather influences are of greater consequence, necessitating advisement on rural freeways where DMSs are instituted. Rural freeway corridors typically have a higher percentage of truck traffic on interstate routes. Safety benefits (reduced crashes) resulting from DMS deployment are foremost in quantitative performance evaluation on rural freeways.

State crash data should be accessed for both fatal and serious injury crashes for a minimum 3-year period before installation of DMSs along a route or corridor and compared to a similar minimum 3-year period of crashes after installation of DMSs. As discussed previously, adjustments must be made for traffic growth and the statistical significance of the difference in crashes tested as previously shown in Figure D-4. Benefits may then be calculated by applying current National Safety Council published costs for traffic crashes by severity category.

Qualitative assessment of DMS performance associated with rural freeway application is affected similar to that previously stated for urban environments. Motorist opinion surveys, whether given personally, by mail-in postcard, by email response, etc., should solicit information from DMS route or corridor users as to observation, credibility, response potential, operational satisfaction, and economic desire to sustain. Examples were previously given of appropriate types of motorist surveys for DMS performance evaluation in Figure 6 and Appendix A. Again, under realistic conditions of limited data availability and agency resources for evaluation (time/manpower), qualitative assessments should not be discounted or understated. Under perceptions and indications of satisfaction with DMSs, performance in fulfilling perceived needs should be weighed heavily as viable benefits to offset costs of DMS installation and maintenance, even if other benefits are non-quantifiable for the reasons previously indicated.

Summary

The above discussion presents some general recommendations on how DMS installations could be evaluated so as to estimate both mobility and safety benefits that result from their deployment. At this time, the recommendations of the research team are to keep the assessments as simplistic as possible in the near term. At the individual driver level, the behavioral responses to DMSs are quite complex and not fully understood at this time. Existing analysis tools do not yet appear to have the computational rigor needed to effectively replicate the real-time situational decision making that appears to occur on the road. Consequently, the efforts to utilize more complicated analysis tools do not appear warranted at this time. Furthermore, the transportation profession does not fully agree that DMS effects should be measured in isolation, but should be evaluated only on the basis of driver satisfaction and usage statistics. Given that the goals and objectives of DMS use are oriented around customer (driver) service rather than operational effects, it can be argued that it is the customer service aspect of operations that should be assessed.

Certainly, it is possible that more sophisticated analysis tools and safety models could eventually be developed and applied to the task of quantifying operational effects of DMSs. If TxDOT desires to improve its ability to quantify DMS impacts in the future with these types of tools, it would be well served to begin thinking about collecting and storing traffic count data specifically during periods of DMS use that could be used for future analyses. While deployment of DMS systems in Texas is extensive, little thought or preparation has previously been given to evaluation of these systems. Operations of any individual DMS were initiated under given protocol at a specific time and evolved through the years. Collection and preservation of the data necessary for rigorous pre- and post-installation evaluation have been sporadic and lacking in consistency. All of these political, situational, and operational factors associated with DMS implementation and operation inhibit the ability to conduct viable quantitative evaluations of DMS performance while increasing the importance and value of benefits associated with qualitative assessments of DMSs.