Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-99/1790-2		

4. Title and Subtitle	5. Report Date
A PROPOSED ITS EVALUATION FRAMEWORK FOR TEXAS	March 1999
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Shawn M. Turner and William R. Stockton	Report 1790-2

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Project No. 0-1790

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080	Research: September 1998 - February 1999
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Project Title: ITS Benefits

16. Abstract

This report presents a proposed intelligent transportation system (ITS) evaluation framework that can be used by the Texas Department of Transportation (TxDOT) in developing evaluation plans for specific ITS applications and deployments in Texas. The research team defines the evaluation framework as a basic model or outline that describes the process and potential measures for evaluating ITS applications. An ITS evaluation framework is distinguished from an evaluation plan, which is deployment specific and identifies specific evaluation measures, data elements, and data collection/estimation methods.

The proposed ITS evaluation framework is based upon measuring the contribution of ITS applications and deployments toward the statewide transportation goals contained in the *Texas Transportation Plan*, which include mobility and accessibility, effectiveness and efficiency, choice and connectivity, safety, environmental and social sensitivity, and economic growth and international trade. This report presents a matrix of evaluation measures corresponding to each of these statewide transportation goals. The report also includes preliminary guidance on developing project-specific ITS evaluation plans using the proposed evaluation framework. The research team recommends that the proposed ITS evaluation framework be applied and tested by using it to develop specific ITS evaluation plans at selected TxDOT district locations.

17. Key Words	18. Distribution Statement
Intelligent Transportation Systems (ITS), Evaluation Framework, Evaluation Measures, Impact Assessment	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	40	

A PROPOSED ITS EVALUATION FRAMEWORK FOR TEXAS

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Report 1790-2
Project Number 0-1790
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Sponsored by the
Texas Department of Transportation
In Cooperation with the
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ACKNOWLEDGMENTS

The authors wish to acknowledge the support and guidance of Darren McDaniel, project director, of TxDOT's Traffic Operations Division. Other members of the project advisory panel during this second year of research include:

- Abed Abukar, Fort Worth District
- Janie Light, Traffic Operations Division, Austin
- Sally Wegmann, Houston District

The comments and suggestions of other members of the Traffic Operations Divisions are also acknowledged here:

- Al Kosik
- Carlos Lopez
- Doug Lowe
- Tom Newbern

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INTRODUCTION

The evaluation of intelligent transportation system (ITS) applications and the resulting documentation of ITS benefits and impacts are a priority area for the Texas Department of Transportation (TxDOT). The ITS evaluations and resulting information will help TxDOT to better understand the impacts of ITS on the transportation system and users of the transportation system, which can help TxDOT make more informed decisions about deploying, designing, and operating ITS applications.

In September 1997, TxDOT initiated a proposed five-year research effort with the Texas Transportation Institute (TTI) and the Center for Transportation Research (CTR) that will focus on evaluating and documenting the benefits and impacts of ITS. More specifically, the research team proposed to accomplish the following:

- document the state-of-the-practice in ITS evaluation and reported benefits;
- develop an ITS evaluation framework for Texas; and
- work with TxDOT in applying and refining the ITS evaluation framework.

The results of the first major task were documented in a previous report (1790-1), which reviews ITS evaluation methods and reported benefits. This report (1790-2) is the next step in the ITS benefits research, i.e., documenting the ITS evaluation framework that has been developed by the research team for use in Texas. The evaluation framework described in this report can be used to develop project-specific evaluation plans.

This brief report is organized into the following major sections:

1. **Introduction -** provides an overview of the research effort and this specific report;

2. **ITS Evaluation Framework and Measures -** summarizes the components of several evaluation frameworks and presents a proposed ITS evaluation framework for Texas; and

3. **Conclusions and Recommendations -** provides recommendations for implementing the evaluation framework and developing project-specific ITS evaluation plans.

ITS EVALUATION FRAMEWORK AND MEASURES

This chapter summarizes the components of several existing ITS evaluation frameworks, including the framework suggested by the U.S. Department of Transportation (DOT) in the National ITS Architecture. The later part of this chapter presents a proposed ITS evaluation framework that can be used to quantify project-specific ITS benefits and impacts in Texas.

WHY EVALUATE ITS?

Before significant detail is provided on specific ITS evaluation methods, it is necessary to review why we evaluate ITS. The reasons for evaluating ITS provide a context for developing an ITS evaluation framework and corresponding measures. Transportation professionals should perform ITS evaluations to:

- **Understand the impacts** - ITS is evaluated to better understand the action-effect relationship between projects and the associated improvement in travel conditions. The effect on transportation systems and users, as well as its social, economic, and environmental impacts, create a comprehensive evaluation package. A better understanding of the impacts of ITS also can help in the following tasks.

- **Quantify the benefits** - Recent trends encourage federal, state, and local governments to measure their performance and quantify the benefits of public/private sector investments (e.g., "return on taxpayer's money"). ITS evaluations concentrated solely on monetizing benefits may be of use to policy makers and other non-technical audiences, but often are focused only on the monetary magnitude of ITS benefits as opposed to the "why?" and "how?" questions typically posed in other transportation system evaluations.

- **Help make future investment decisions** - ITS evaluations can help to optimize public sector investments by providing information about the ideal conditions for implementation and likely range of impacts, which can be used to make future investment or deployment decisions. Information from ITS evaluations can also be used by the private sector to make business process decisions.

- **Optimize existing system operation or design** - ITS evaluations can help to identify areas of improvement for existing operations or systems, enabling operators or designers to better manage, correct, improve, or "fine-tune" system operation or design.

Figure 1 shows the hypothesized evolution of ITS evaluations. To date, many ITS evaluations have been focused primarily on the first function (i.e., quantifying the impacts of ITS). A focus on the absolute monetary benefits of ITS has been necessary to convince policy makers and other non-technical decision makers that ITS technologies and applications are mature and ready to be deployed. Although these benefit studies have been necessary to convince policy and decision makers that ITS can be a worthwhile investment, the research team suggests that the information from these benefit studies has contributed marginally to a much-needed broad database that would help in making future investment decisions, and even less in optimizing transportation system operation. Based upon Figure 1, the authors suggest that to better meet the emerging needs in transportation, ITS evaluations will need to concentrate on the "why?" and "how?" of ITS impacts (and not just the absolute monetary magnitude) to help guide future investment decisions and optimize system operation.

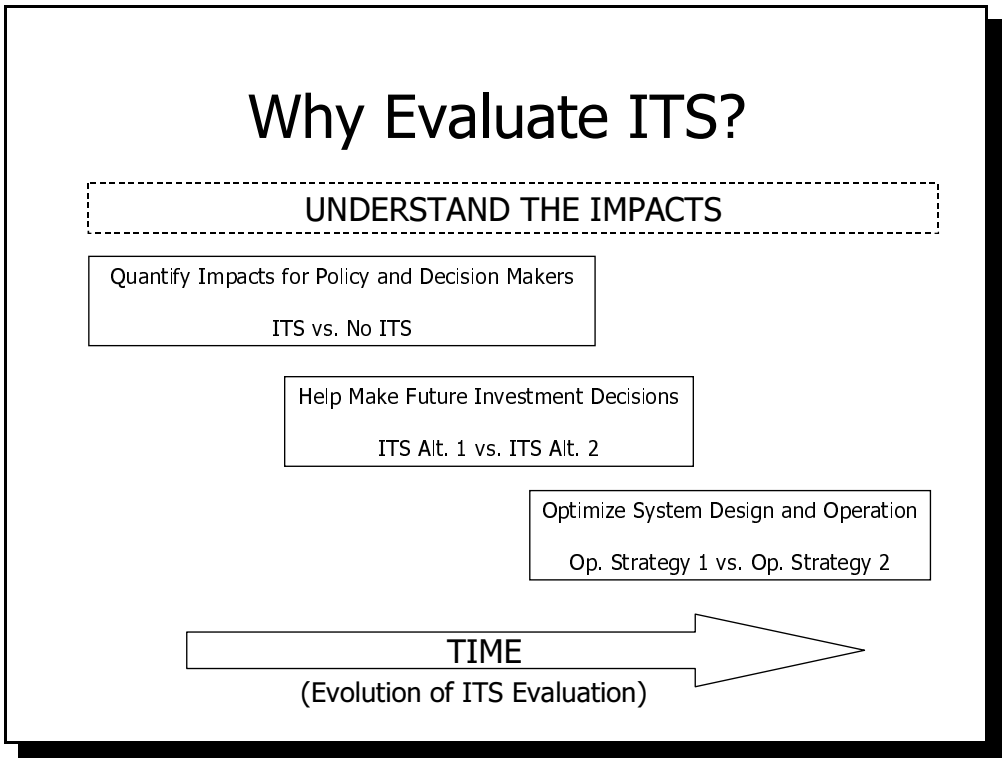

Figure 1. Evolution of ITS Evaluations

GENERIC ITS EVALUATION FRAMEWORK

A generic, goals-based transportation evaluation framework is illustrated in Figure 2. This common method of evaluating complex transportation systems consists of measuring the progress or contribution toward stated transportation goals and objectives. The progress or contribution toward stated goals is quantified by selecting evaluation measures (a.k.a. metrics, measures of effectiveness, performance measures) that directly relate to the goals and objectives.

This report focuses on the evaluation framework, which consists of the following:

- **Designation of transportation goals and objectives -** determine goals and objectives through a consensus process involving all stakeholders relevant to transportation; and

- **Enumeration of evaluation measures -** enumerate a matrix or "menu" of evaluation measures that can be used to gauge progress toward various transportation goals and objectives.

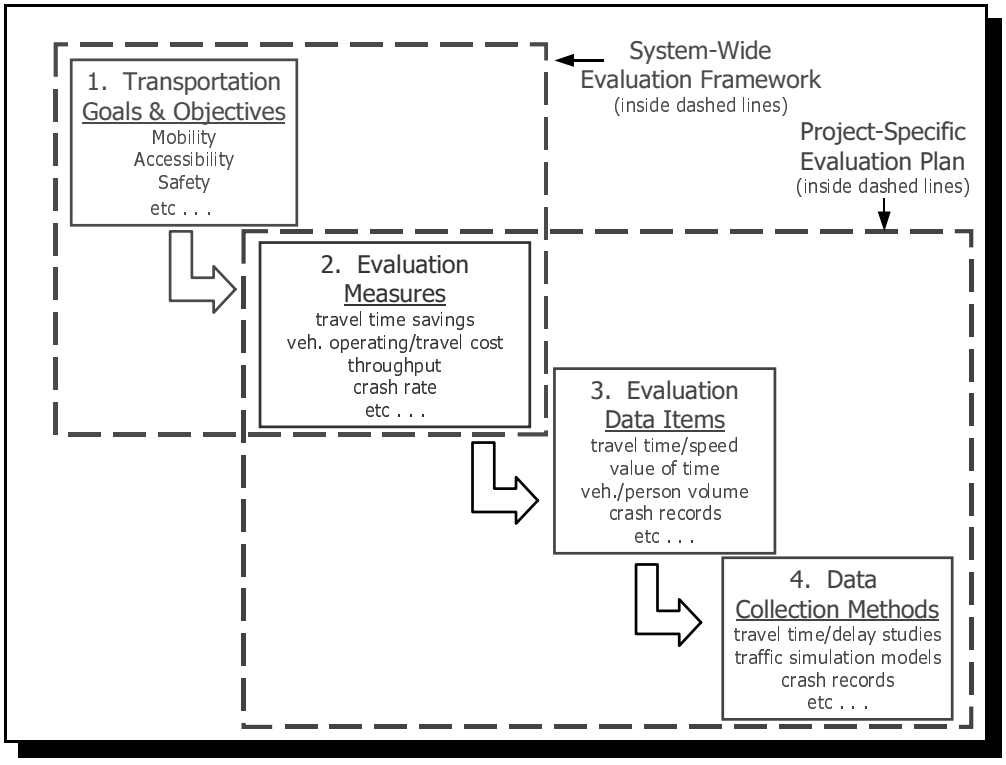

Figure 2. Goals-Based Transportation Evaluation

An evaluation plan, as shown in Figure 2, is more project specific and is developed given specific ITS deployment plans and implementation details. The evaluation plan consists of the following:

- **Selection of specific evaluation measures -** select specific evaluation measures from the matrix of measures enumerated in the framework (i.e., measures are selected based on the ITS deployment's anticipated contribution toward the framework's goals);

- **Determination of evaluation data items -** identify data items that are necessary to calculate the selected evaluation measures; and

- **Data collection/estimation methods -** identify and select data collection and/or estimation methods that are necessary to support the needed evaluation data and measures.

The U.S. DOT has applied a goals-based framework in the national ITS evaluation guidance developed thus far. For example, the *National ITS Program Plan* (1), which is designed to guide the development and deployment of ITS in the United States, presented six goals (shown below with supporting objectives) for the national ITS program:

1. **Improve the safety of the nation's transportation system**
   - reduce number and severity of fatalities and injuries
   - reduce severity of collisions

2. **Increase the operational efficiency and capacity of the surface transportation system**
   - reduce disruptions due to incidents
   - improve the level of service and convenience provided to travelers
   - increase roadway capacity

3. **Reduce energy and environmental costs associated with traffic congestion**
   - reduce harmful emissions per unit of travel
   - reduce energy consumption per unit of travel

4. **Enhance present and future productivity**
   - reduce costs incurred by fleet operators and others
   - reduce travel time
   - improve transportation systems planning and management

5. **Enhance the personal mobility and the convenience and comfort of the surface transportation system**
    - provide access to pre-trip and en-route information
    - improve the security of travel
    - reduce traveler stress

6. **Create an environment in which the development and deployment of ITS can flourish**
    - support the establishment of a significant U.S.-based industry for hardware, software, and services

In developing the National ITS Architecture, the U.S. DOT developed metrics (or evaluation measures) that are related to these six ITS goals (2). Table 1 presents a matrix or "menu" of possible measures that can be used to evaluate ITS (i.e., ITS evaluations need not quantify every measure in this matrix). The ITS Joint Program Office of the U.S. DOT advocates the use of what has been termed "a few good measures," which consists of a "few measures robust enough to represent the goals and objectives of the entire ITS program, yet are few enough to be affordable in tracking the ITS program on a yearly basis" (3). These "few good measures" are as follows:

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

Table 1. ITS Benefits Matrix Based Upon U.S. DOT's ITS Goals

ITS Goal	Related Metric
Increase Transportation System Efficiency and Capacity	traffic flows/volumes/number of vehicles lane carrying capacity volume to capacity ratio vehicle hours of delay queue lengths number of stops incident-related capacity restrictions average vehicle occupancy use of transit and HOV modes intermodal transfer time infrastructure operating costs vehicle operating costs
Enhance Mobility	number of trips taken individual travel time individual travel time variability congestion and incident-related delay travel cost vehicle miles traveled (VMT) number of trip end opportunities number of accidents number of security incidents exposure to accidents and incidents
Improve Safety	number of incidents number of accidents number of injuries number of fatalities time between incident and notification time between notification and response time between response and arrival at scene time between arrival and clearance medical costs property damage insurance costs
Reduce Energy Consumption and Environmental Costs	NO_x emissions SO_x emissions CO emissions VOC emissions liters of fuel consumed vehicle fuel efficiency
Increase Economic Productivity	travel time savings operating cost savings administrative and regulatory cost savings manpower savings vehicle maintenance and depreciation information-gathering costs integration of transportation systems
Create an Environment for an ITS Market	ITS sector jobs ITS sector output ITS sector exports

Source: U.S. DOT, (2), p. 61

The guidance in the National ITS Architecture documents also relates specific ITS user services and market packages to identifiable ITS goals and objectives. Through numerous tables and flowcharts, the "Final Performance and Benefits Summary" (2) of the Architecture illustrates the direct linkage between user services and market packages, transportation goals and objectives, and evaluation measures (Figure 3). In the National ITS Architecture, market packages are defined as an accessible, deployment-oriented architecture perspective that are tailored to fit - separately or in combination - real world transportation problems and needs. For example, assume that we wish to evaluate a freeway control system market package (which includes the communications and roadside equipment to support ramp control, lane controls, and interchange control for freeways). Figure 4 illustrates the metrics that can be used to evaluate the freeway control system, as well as referring to the original stated ITS goals shown in Table 1. This figure has been combined from several figures contained in the Appendix of the "Final Performance and Benefits Summary" of the National ITS Architecture.

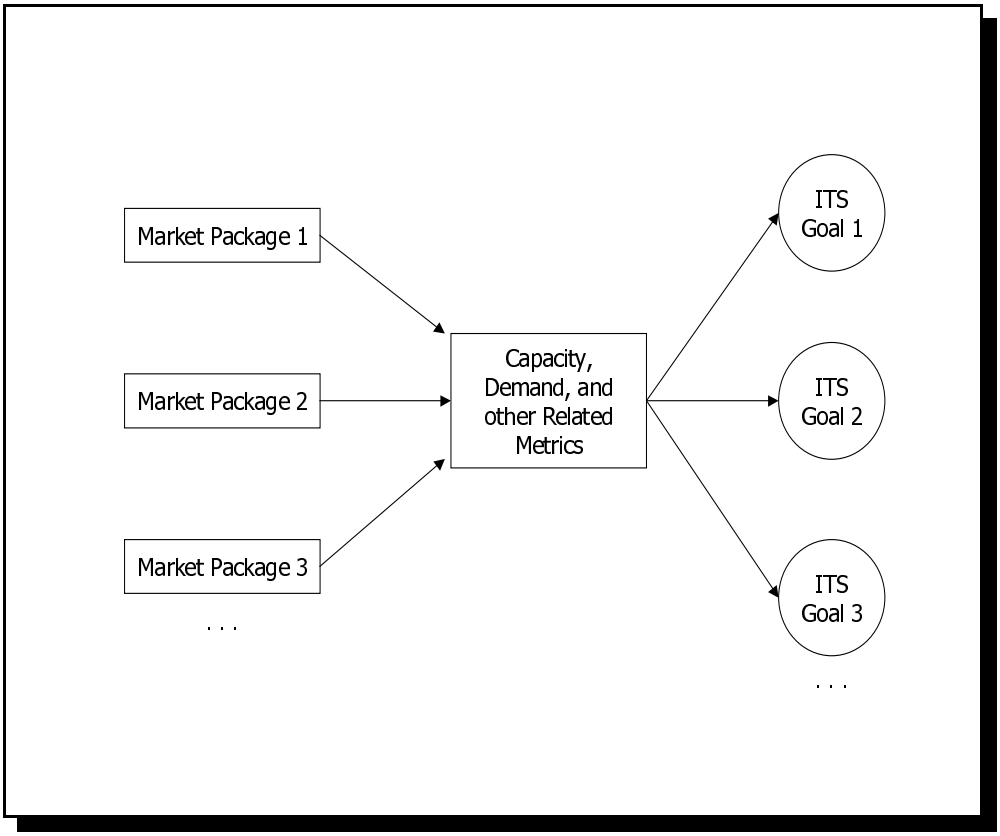

Figure 3. Benefits Flow Diagram Schematic
(Source: U.S. DOT, (2), p. 66)

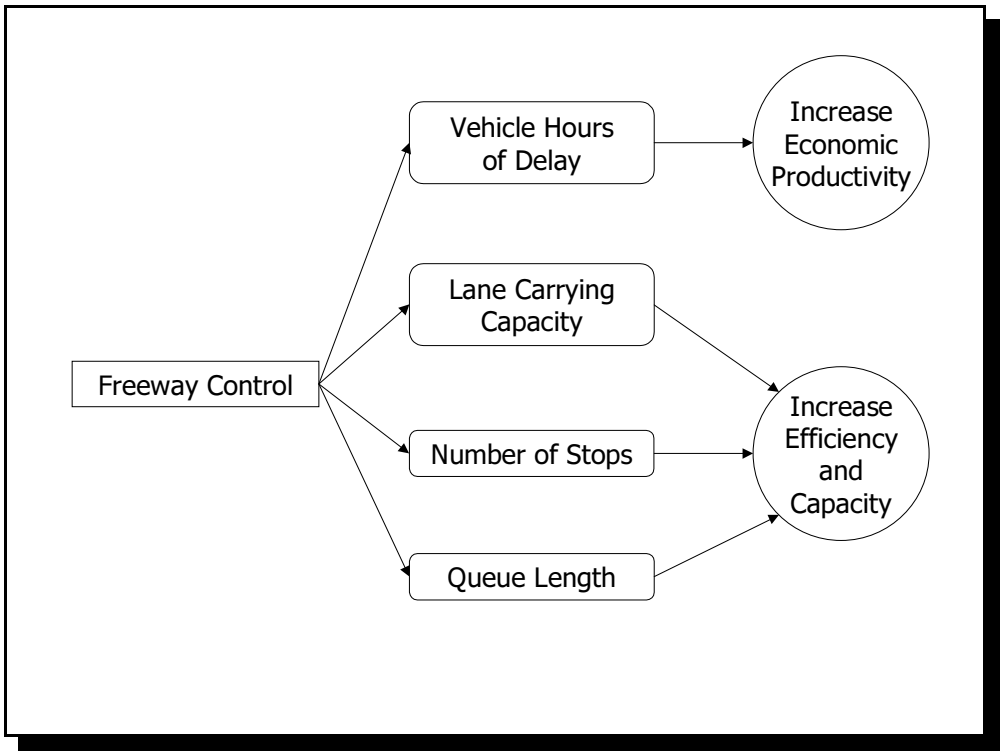

Figure 4. Benefit Flow Diagram for Freeway Control Market Package
(Source: adapted from U.S. DOT, (2), Appendix A)

OTHER CONSIDERATIONS IN ITS EVALUATIONS

To date, most of the national guidance on ITS evaluation has focused on defining an appropriate evaluation framework. Several resource documents are available:

- *Final Performance and Benefits Summary,* National ITS Architecture (2)
- *Metropolitan Model Deployment Initiative National Evaluation Strategy* (4)
- *Integrating Intelligent Transportation Systems within the Transportation Planning Process: An Interim Handbook* (5)
- *Advanced Public Transportation Systems: Evaluation Guidelines* (6)
- *Guidelines for IVHS Operational Test Evaluation Plans: Advanced Traveler Information Systems and Advanced Traffic Management Systems* (7)

There are also numerous evaluation plan documents available through the ITS Joint Program Office's Electronic Document Library (EDL) at http://www.its.dot.gov/cyberdocs/welcome.htm that have been prepared for ITS deployments nationwide. These location-specific ITS evaluation plans provide examples of how other agencies have addressed the evaluation details in their evaluation plans. The following sections discuss several ITS evaluation aspects that should be considered in addition to the national guidance provided above.

Defining Goals

The transportation system or program goals are of utmost importance in defining an ITS evaluation framework, as the evaluation measures are selected based upon the desired outcome (goals/objectives). Therefore, it is critical that the transportation goals and objectives are developed through a consensus process that truly involves all stakeholders, including all relevant public agencies and affected private sector groups, as well as the general public. The transportation goals and objectives are typically developed for state and regional transportation plans, which can serve as an excellent resource for defining how ITS fits into the larger regional or statewide transportation plan.

The previous section presented the national ITS program goals and objectives (Table 1), and similar goals exist in Texas' statewide transportation plan. These goal statements typically include the following as desired outcomes: enhance mobility/accessibility, increase efficiency, improve safety, reduce environmental and social impacts, and increase economic productivity. However, there is some debate at the national level about the desirability of other transportation goals (8), such as the following:

- **Sustainability -** The effective use of resources to meet today's needs without compromising the ability of future generations to meet their needs. The concept of sustainability encompasses diverse issues such as suburban sprawl and induced travel from highway capacity expansion.

- **Equity -** The fair geographic and socioeconomic distribution of resources and the corresponding benefits.

Output vs. Outcome (or Supply vs. Demand-Side) Evaluation Measures

There is a need to distinguish between two basic types of evaluation measures that are commonly used in ITS evaluations: output and outcome measures.

Output measures (also known as supply-side or efficiency measures) characterize the aggregate traffic flow, speeds, or travel time on the transportation network. Examples of output or efficiency measures include traffic volume per lane, vehicle-miles of travel (VMT), or total vehicle delay. Output measures are typically aggregate in nature (averaged over many vehicles or roadways) and typically correspond to a transportation facility.

Outcome measures (also known as demand-side or effectiveness measures) characterize the impacts at the individual traveler or company level. Examples of outcome measures include improved mobility and travel opportunities, individual travel times and trip time reliability, or travel costs. Outcome or effectiveness measures typically characterize the effects of transportation on impacted groups.

Traditional traffic engineering analyses have focused almost solely on output measures, which are more closely aligned to typical engineering processes, and the data to support output measures are relatively easy to collect. For example, vehicle throughput along a freeway corridor is: 1) considered an output measure, 2) a fundamental element of traffic flow theory, and 3) relatively easy to collect. Outcome measures are more oriented toward the experiences or perceptions of the individual traveler, shipper, or transport agency. As such, outcome measures are more difficult to measure than output measures. For example, travel time savings by mode is an outcome measure that is more difficult to measure than vehicle throughput at a freeway location.

In some cases, output measures may lead to outcome measures, but most processes estimating performance measures can not make this assumption. For example, increased vehicle throughput along a freeway corridor could lead to travel time savings along that corridor, but perhaps the traveler or shipper experiences even more severe problems at the beginning or end of their trip.

It is necessary to distinguish between output and outcome measures in ITS evaluations for several reasons:

- Output measures are typically aggregate facility statistics, and as such, are unable to capture the dynamics of individual traveler responses (as outcome measures typically do);

- Outcome measures are more closely associated with specific transportation goals, such as mobility, accessibility, or safety; and

- Output measures are more easily collected/measured because of their aggregate nature, whereas outcome measures require measurement at the individual traveler or company level.

For these reasons, it is necessary to achieve an appropriate balance between output and outcome measures in ITS evaluations (9).

Impacted Groups

Many traditional ITS benefit analyses have concentrated mainly on transportation user benefits, such as total delay, travel time and speed, or number and severity of crashes. In reality, however, there are several other groups or sub-groups that are impacted or affected by the implementation of ITS. These groups, the benefits or impacts to whom should be considered in ITS evaluations, include the following (9):

- various user groups (e.g., urban, rural, suburban, elderly, commuters, etc.);
- non-users (e.g., residents, property and business owners, etc.);
- public agency operators (e.g., police, fire, emergency response, DOT, etc.); and

- private sector operators and industry (e.g., trucking, hardware/software manufacturers, etc.).

Time Frame of Occurrence

ITS evaluation plans should also recognize the time frame of occurrence for benefits and impacts of ITS (9). Some of the impacts, such as increased throughput or decreased travel time, may be seen almost immediately. Other impacts, such as changes in land use or economic productivity, may not be evident for many years. As an example, evaluation plans might use these or similar time frame categories:

- short term - benefits/impacts occurring within two years after implementation;
- medium term - benefits/impacts occurring between two to five years after implementation; and
- long term - benefits/impacts occurring five years or more after implementation.

Complexity and Cost of ITS Evaluations

The research team found significant variance in the complexity of ITS evaluations. It was concluded that the needed complexity of the evaluation depends upon the intended end use of evaluation results (among other factors as well). For example, one may need an extremely sophisticated evaluation framework if the true economic impact to society is to be determined. A less complex evaluation framework may suffice, however, if the results are used to prioritize ITS projects or track annual results or progress toward goals.

The cost of ITS evaluation may also be a limiting factor in terms of complexity and sophistication. In some cases, concerns about the cost of ITS evaluations have even prevented them from being conducted. Complex evaluation frameworks may appear conceptually sound on paper but be prohibitively expensive to perform, thus leading to little or no project evaluation. The research team feels there is a need to strike a balance between evaluation framework complexity and ability to collect and/or model the relevant evaluation data.

A PROPOSED ITS EVALUATION FRAMEWORK FOR TEXAS

This section describes the approach used to develop an ITS evaluation framework for Texas, as well as the resulting evaluation framework and measures. The research team used existing national guidance on ITS evaluation and several recent or ongoing research efforts to define this framework. The evaluation framework is based on the goals for Texas' transportation system as outlined in the 1994 *Texas Transportation Plan* (10). The section concludes by presenting the data elements in the ITS evaluation framework that potentially can be obtained from ITS surveillance and sensor systems.

Texas Transportation Goals and Objectives

Because the research team selected a goals-based evaluation framework, the first step in defining the ITS evaluation framework was establishing or referencing the appropriate goals that ITS applications should satisfy. The researchers concluded that the existing transportation goals and objectives from TxDOT's long-range transportation plan (*Texas Transportation Plan*) should be used for ITS applications. Table 2 relates the goals and objectives from the *Texas Transportation Plan* to the U.S. DOT's national ITS goals, as well as highlighting proposed evaluation measures.

Developing Evaluation Measures

Based on the goals and objectives shown in Table 2, the research team developed evaluation measures that are capable of indicating progress toward each goal. The last column in Table 2 references the location of these evaluation measures in Tables 3 through 8. These evaluation measures were selected from existing U.S. DOT guidance on ITS evaluation, as well as several other reference documents related to transportation system performance measurement (11,12,13,14,15). As indicated in the previous section, there are several considerations when developing and selecting evaluation measures. The three columns in Tables 3 through 8 contain additional information about each evaluation measure that relates to the type of measure (output vs. outcome), the impacted user groups, and the time frame of occurrence of impacts.

Table 2. Texas Transportation Goals (from the Texas Transportation Plan, 1994) and Proposed Evaluation Measures

Goals	Objective(s)	Recommended "Core" Evaluation Measure(s)	Evaluation Measures "Menu" Table
Mobility and Accessibility (U.S. DOT: Enhance Mobility)	To develop a multi-modal transportation system that meets the mobility and accessibility needs of all Texans.	• travel time savings • customer satisfaction • vehicle operating/travel costs	Table 3
Effectiveness and Efficiency (U.S. DOT: Increase Transp. System Efficiency and Capacity)	To maximize the use of existing transportation facilities and services and ensure that investment decisions are based on efficient solutions.	• benefit-cost ratio • vehicle/person throughput	Table 4
Choice and Connectivity	To maximize the modal options available to individual and business transportation system users and to ensure that all modes are efficiently connected to provide for easy transfers and timeliness.	• ability to choose alternative travel modes • connectivity of travel modes	Table 5
Safety (U.S. DOT: Improve Safety)	To ensure that all modes of transportation and transfers between modes are safe for transportation users and providers.	• number and severity of crashes • number of fatalities	Table 6
Environmental and Social Sensitivity (U.S. DOT: Reduce Energy Consumption and Environmental Costs)	To provide a transportation system that is environmentally sound, energy efficient, and sensitive to community needs and impacts.	• mobile source emissions • fuel consumption • impact on natural habitat • community acceptance • equitable distribution of benefits/impacts	Table 7
Economic Growth and International Trade (U.S. DOT: Increase Economic Productivity)	To build a transportation system that maximizes opportunity for economic growth, international trade, and tourism.	• travel time savings • operating cost savings • administrative and regulatory cost savings	Table 8

Table 3. Evaluation Measures for Mobility and Accessibility

Mobility and Accessibility Evaluation Measures	Impacted Groups [a]	Time Frame of Occurrence [b]
QUALITY OF EXISTING TRAVEL		
1. travel time savings [c]	users, private sector	short term
2. customer satisfaction [c]	users, private sector	short, medium
3. individual travel/trip time	users, private sector	short term
4. individual travel/trip time reliability	users, private sector	short term
5. congestion and incident-related delay time	users, private sector	short term
6. vehicle-, person-miles of travel in congested ranges	users, private sector	short, medium
7. vehicle-, person-hours of travel in congested ranges	users, private sector	short, medium
8. congestion level/indices	users, private sector	short, medium
9. speed profiles	users, private sector	short, medium
10. comfort, stress, fatigue, confusion, etc.	users, private sector	short, medium
PROPENSITY FOR ADDITIONAL TRAVEL		
1. vehicle operating/travel costs [c]	users, private sector	short, medium
2. number of trips taken	users, private sector	short, medium
3. vehicle-, person-miles of travel	users, private sector	short, medium
4. vehicle-, person-hours of travel	users, private sector	short, medium
5. number of travel/trip end opportunities	users, private sector	short, medium, long
6. change in individual trip distance	users, private sector	short, medium
7. change in individual travel patterns	users, private sector	short, medium, long
ABILITY TO ACCESS LAND USES		
1. % population within "x" minutes travel of employment center	users, private sector	medium, long
2. % population within "x" minutes travel of basic shopping center	users, private sector	medium, long
3. % population within "x" minutes travel of retail shopping center	users, private sector	medium, long

Notes: [a] **Impacted user groups:** users, non-users, public agency, and private sector.

[b] **Time frame of occurrence:** short (less than 2 years), medium (2 to 5 years), and long term (more than 5 years).

[c] Evaluation measure (**shown in bold**) included in the U.S. DOT's "few good measures" list.

Table 4. Evaluation Measures for Effectiveness and Efficiency

Effectiveness and Efficiency Evaluation Measures	Impacted Groups [a]	Time Frame of Occurrence [b]
EFFECTIVENESS		
1. benefit-cost ratio	all groups	short, medium, long
2. cost per new person trip	users	short, medium
3. user willingness to pay	users, private sector	short, medium, long
4. user estimate of effectiveness	users, private sector	short, medium
EFFICIENCY		
1. throughput [c] (traffic flows, volume)	users, private sector	short term
2. increases in freeway and arterial lane-carrying capacity	users, private sector	short term
3. vehicle-hours of delay	users, private sector	short term
4. queue lengths/time in queue	users, private sector	short term
5. number of stops	users, private sector	short term
6. average vehicle occupancy	users	short, medium
7. use of transit and HOV modes	users	short, medium
8. use of bicycling/walking modes	users	short, medium
9. infrastructure operating costs	users, public agency	short, medium, long
10. volume of traffic rerouted	users, private sector	short term
11. incident detection/verification time by incident type/severity	users, private sector	short term
12. incident response time by incident type/severity	users, private sector	short term
13. incident clearance time by incident type/severity	users, private sector	short term
14. time periods and locations of incident occurrences	users, private sector	short term

Notes: [a] **Impacted user groups:** users, non-users, public agency, and private sector.

[b] **Time frame of occurrence:** short (less than 2 years), medium (2 to 5 years), and long term (more than 5 years).

[c] Evaluation measure (**shown in bold**) included in the U.S. DOT's "few good measures" list.

Table 5. Evaluation Measures for Choice and Connectivity

Choice and Connectivity Evaluation Measures	Impacted Groups [a]	Time Frame of Occurrence [b]
CHOICE		
1. ability to choose convenient alternative modes	users	short, medium, long
2. amount, source, and quality of traveler information	users, private sector	short term
3. frequency of individual traveler route diversion	users, private sector	short term
4. frequency of individual traveler trip time changes	users, private sector	short term
CONNECTIVITY		
1. intermodal transfer time	users, private sector	short, medium
2. schedule adherence	users, private sector	short term
3. relative connectivity of modal systems, between modal systems	users	short, medium

Notes: [a] **Impacted user groups:** users, non-users, public agency, and private sector.
[b] **Time frame of occurrence:** short (less than 2 years), medium (2 to 5 years), and long term (more than 5 years).

Table 6. Evaluation Measures for Safety

Safety Evaluation Measures	Impacted Groups [a]	Time Frame of Occurrence [b]
SAFETY		
1. number and severity of crashes [c]	users, private sector	short, medium
2. number of fatalities [c]	users, private sector	short, medium
3. number and severity of other incidents/secondary crashes	users, private sector	short, medium
4. medical/property damage/insurance costs	all groups	short, medium
5. number of vehicle thefts	users, non-users	short term
6. number of personal security incidents	users, private sector	short term

Notes: [a] **Impacted user groups:** users, non-users, public agency, and private sector.
[b] **Time frame of occurrence:** short (less than 2 years), medium (2 to 5 years), and long term (more than 5 years).
[c] Evaluation measure (**shown in bold**) included in the U.S. DOT's "few good measures" list.

Table 7. Evaluation Measures for Environmental and Social Sensitivity

Environmental and Social Sensitivity Evaluation Measures	Impacted Groups [a]	Time Frame of Occurrence [b]
ENVIRONMENTAL IMPACTS		
1. mobile source emissions levels (NO_x, SO_x, CO, VOC)	all groups	short, medium
2. energy/fuel consumption	all groups	short, medium
3. vehicle fuel efficiency	all groups	medium, long
4. impact on land, water, animal, ecosystem, and natural habitat	non-users, users	medium, long
5. hazardous wastes/cargo	all groups	short, medium
SOCIAL IMPACTS		
1. noise pollution	non-users, users	short term
2. visual quality/aesthetics	non-users, users	short, medium
3. reduced right-of-way requirements	non-users, users	short term
4. neighborhood traffic intrusiveness/community acceptance	non-users	short, medium, long
5. public reaction	non-users	short, medium, long
6. geographic and socioeconomic distribution of ITS benefits and services	users, non-users	short, medium, long
7. number of displaced persons/homes/businesses	non-users, users	short term
8. effects on land use efficiency/suburban sprawl	all groups	medium, long

Notes: [a] **Impacted user groups:** users, non-users, public agency, and private sector.
[b] **Time frame of occurrence:** short (less than 2 years), medium (2 to 5 years), and long term (more than 5 years).

Table 8. Evaluation Measures for Economic Growth and International Trade

Economic Growth and International Trade Evaluation Measures	Impacted Groups [b]	Time Frame of Occurrence [c]
ECONOMIC GROWTH AND INTERNATIONAL TRADE		
1. **travel time savings** [c]	private sector	short, medium
2. **operating cost savings** [c]	private sector, public	short, medium
3. **administrative and regulatory cost savings** [c]	public agency, private	short, medium
4. manpower savings	private sector, public	short, medium
5. vehicle maintenance and depreciation costs	private sector, public	short, medium
6. information gathering costs	public agency, private	short, medium
7. integration of transportation systems	users, public agency	short, medium
8. increased access to labor, materials, markets	private sector	medium, long

Notes: [a] **Impacted user groups:** users, non-users, public agency, and private sector.
[b] **Time frame of occurrence:** short (less than 2 years), medium (2 to 5 years), and long term (more than 5 years).
[c] Evaluation measure (**shown in bold**) included in the U.S. DOT's "few good measures" list.

Data Collection and Estimation Methods to Support Evaluation Measures

The primary intent of this research report is to present an ITS evaluation framework, which includes appropriate measures and the evaluation context (Figure 2). For this reason, specific data collection or estimation methods to support the calculation of evaluation measures are not provided within this report. The reader is referred to the following references for more information about data collection and estimation methods to support ITS evaluation measures:

- *Manual of Transportation Engineering Studies* (16)
- *Highway Capacity Manual* (17)
- *Travel Time Data Collection Handbook* (18)
- *Travel Survey Manual* (19)

In many cases, surveillance and sensor systems deployed for ITS can provide a significant amount of data for ITS evaluations (20) (assuming the data is collected and stored properly). The problem, however, is that the archived ITS data is typically only available once the core functions of ITS have been deployed, thereby lessening the opportunity to collect "before conditions" data. Depending upon the deployment and equipment installation schedule, surveillance and sensor systems could be used during acceptance testing of other components to collect "before conditions" data. At the least, archived data from ITS can be used for simulation model calibration and "after conditions" data (provided that archived ITS data is comparable to data

collected with different methods during "before conditions"). Table 9 presents data elements that can be incorporated into ITS evaluations and may be available from ITS applications that have been deployed consistent with the National ITS Architecture.

Table 9. Potential Contribution of Archived ITS Data to ITS Evaluation

Data Source	Potential Data Elements	Relevant Evaluation Goals
freeway and arterial surveillance sensor data (inductance loop and other non-intrusive detectors, weigh-in-motion systems, etc.)	vehicle volume vehicle speed vehicle classification/weight estimated travel time	Mobility and Accessibility Effectiveness and Efficiency Environmental/Social Sensitivity Economic Growth and Intl. Trade
video surveillance data	vehicle occupancy vehicle classification vehicle stops queue length	Effectiveness and Efficiency Safety Environmental/Social Sensitivity Economic Growth and Intl. Trade
transit systems	passenger boardings trip patterns trip distances schedule adherence rideshare/paratransit requests	Mobility and Accessibility Effectiveness and Efficiency Choice and Connectivity
incident management logs	incident response times cause, type, extent, and duration of incidents	Mobility and Accessibility Effectiveness and Efficiency Safety
emissions management systems	emissions levels	Environmental/Social Sensitivity
commercial vehicle operations administrative and clearance systems	commercial vehicle counts commercial vehicle identification type/quantity of freight	Mobility and Accessibility Safety Economic Growth and Intl. Trade
probe vehicle data	travel time/travel time reliability travel distance and patterns	Mobility and Accessibility Effectiveness and Efficiency Choice and Connectivity

Source: adapted from (20), Table 1.3

Developing an ITS Evaluation Plan Using the Framework

The previous sections presented an ITS evaluation framework that can be used to evaluate ITS projects or applications. The framework (Figure 2) includes the establishment of ITS goals and objectives, as well as a matrix of evaluation measures that can be used to gauge progress toward these goals and objectives. The framework does not include specific recommendations for the application of these evaluation measures, nor the necessary data collection or estimation methods to support the calculation of these measures. Because conditions and implementation details vary considerably between deployments, these detailed procedures and requirements should be defined in an ITS evaluation plan that is prepared for each specific deployment.

The steps shown in Figure 5 and below for developing an ITS evaluation plan assume that ITS deployment planning has been conducted. If not, the following steps are necessary:

Step 0a. Identify the problem, deficiency, or opportunity to be addressed.
Step 0b. Develop goals and/or objectives that describe the expected improvement.
Step 0c. Identify market packages or user services to be deployed based upon desired goals and/or objectives (i.e., user services are ITS strategies with a customer-orientation, while market packages are ITS strategies with an equipment-orientation).

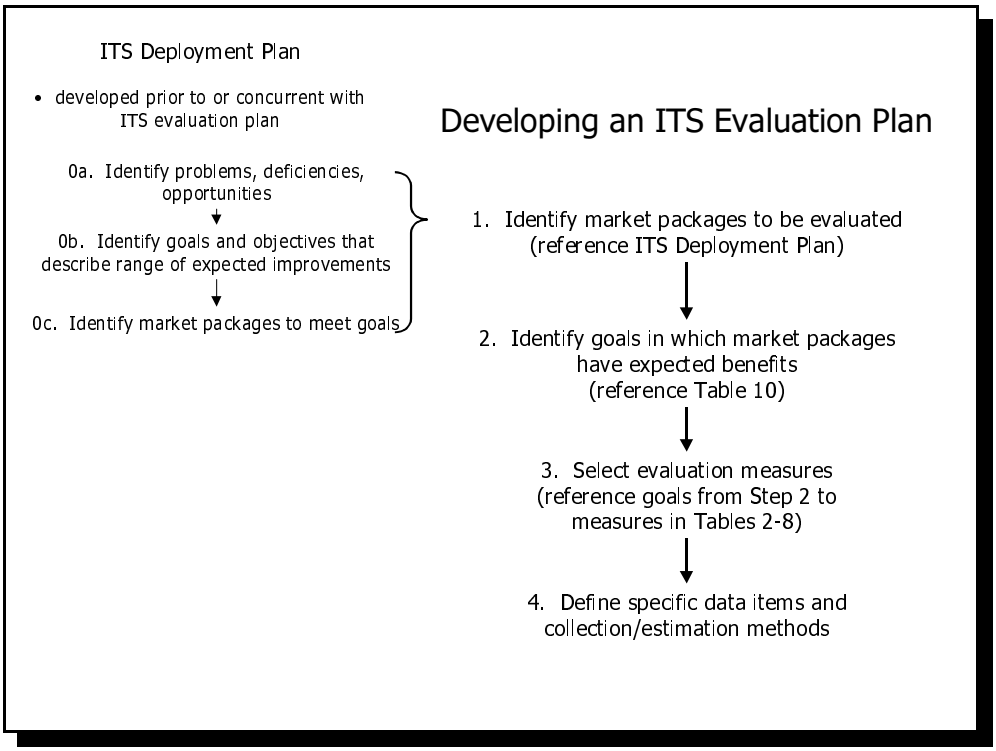

Figure 5. Developing an ITS Evaluation Plan

Once the basic ITS deployment plan has been established, the following steps can be taken in developing a more detailed ITS evaluation plan:

Step 1. **Identify the Market Packages Planned for Deployment That Will Be Evaluated -** Table 10 contains a listing of the market packages as identified in the National ITS Architecture. Evaluators should identify all market packages in this table that will be deployed and evaluated.

Step 2. **Identify the Goals in Which the Market Packages Have Expected Benefits -** For each market package in Table 10 to be deployed and evaluated, evaluators should note the goals in which benefits or impacts are expected or anticipated.

Step 3. **Cross-Reference the Goals and Select Appropriate Evaluation Measures -** For each market package in Table 10 to be deployed and evaluated, evaluators should cross-reference the goals to those shown in Tables 2 through 8. Evaluators should select measures from Tables 2 through 8 that correspond to the anticipated benefits from the specific deployment characteristics and local conditions. Table 2 contains "core" evaluation measures that are recommended as a minimum for each deployment goal. Tables 3 through 8 present an entire "menu" of evaluation measures that could be used in addition to the "core" evaluation measures in Table 2.

Step 4. **Define Specific Data Items and Collection and/or Estimation Methods Based on Local Deployment -** Once the evaluation measures for each goal and market package are selected, evaluators should develop a data collection and/or estimation plan that outlines how the data to support the evaluation measures are to be collected and/or estimated. The data collection plan will be used to guide the data collection and analysis portion of the evaluation.

Table 10. Benefits of Market Packages for Achieving Texas Transportation Goals

Market Packages		Contribution to Texas Transportation Goals					
		Mobility and Accessibility	Effectiveness and Efficiency	Choice and Connectivity	Safety	Env. and Social Sensitivity	Economic Growth and Intl. Trade
APTS	Transit Vehicle Tracking	**		**		*	*
	Fixed-Route Operations	**		**		*	*
	Demand-Responsive Operations	**		*		*	*
	Passenger and Fare Management						**
	Transit Security				**		
	Transit Maintenance						*
	Multi-modal Coordination	*		***			*
ATIS	Broadcast Traveler Info	**		**		*	
	Interactive Traveler Info	***	**	**		*	
	Autonomous Route Guidance	***	**				
	Dynamic Route Guidance	***	**		*	*	
	ISP-Based Route Guidance	***	**		*	*	
	Integrated Transportation Mgmt/Route Guidance	***	***		*	**	
	Yellow Pages and Reservation	*		*			
	Dynamic Ridesharing	*	**	*		*	
	In Vehicle Signing	*		*	*		
ATMS	Network Surveillance	*		*		*	
	Probe Surveillance	*		*		*	
	Surface Street Control	***	**		**	**	
	Freeway Control	***	**		*	**	
	Regional Traffic Control	***	***		**	***	
	HOV and Reversible Lane Management	**				*	
	Incident Management System	**	**		**	***	
	Traffic Information Dissemination	*	**	**		*	
	Traffic Network Performance Evaluation	**	**				
	Dynamic Toll/Parking Fee Management						**
	Emissions and Environ. Hazards Sensing					***	
	Virtual TMC and Smart Probe Data	*				*	*

Note: * = low benefit; ** = moderate benefit; *** = high benefit.

Table 10. Benefits of Market Packages for Achieving Texas Transportation Goals (Cont.)

Market Packages		Contribution to Texas Transportation Goals					
		Mobility and Accessibility	Effectiveness and Efficiency	Choice and Connectivity	Safety	Env. and Social Sensitivity	Economic Growth and Intl. Trade
	Fleet Administration	***		**			***
	Freight Administration	***		**			***
	Electronic Clearance	***	**				***
	CV Administrative Processes			**			**
	International Border Electronic Clearance	***	**				***
	Weigh-In-Motion	***	**				***
	CVO Fleet Maintenance		*	**	**		**
	HAZMAT Management		*		**		**
	Roadside CVO Safety	**			**		**
	On-board CVO Safety				***		**
	Vehicle Safety Monitoring				***		
	Driver Safety Monitoring				***		
	Longitudinal Safety Warning				***		
	Lateral Safety Warning				***		
	Intersection Safety Warning				***		
	Pre-Crash Restraint Deployment				***		
	Driver Visibility Improvement				***		
	Advanced Vehicle Longitudinal Control	*	**		***		
	Advanced Vehicle Lateral Control	*	**		***		
	Intersection Collision Avoidance				***		
	Automated Highway System	***	***		***		
	Emergency Response				***	*	**
	Emergency Routing				***	*	**
	Mayday Support				***		*
	ITS Planning	**	**	**	**	**	**

Note: * = low benefit; ** = moderate benefit; *** = high benefit.
Source: adapted from U.S. DOT, (2), pp. 9-10.

CONCLUSIONS AND RECOMMENDATIONS

This research report presented a recommended framework for evaluating the benefits and impacts of ITS applications. The recommended framework is based largely on national guidance for ITS evaluations contained in the National ITS Architecture, with some adaptations for application in Texas. The recommended ITS evaluation framework is based upon evaluating progress toward the goals as stated in the Texas Transportation Plan:

- mobility and accessibility;
- effectiveness and efficiency;
- choice and connectivity;
- safety;
- environmental and social sensitivity; and
- economic growth and international trade.

These goals and the corresponding objectives were used to develop evaluation measures that can be applied in the context of project-specific evaluations. Because deployments and implementation elements can vary dramatically by location, no specific information (other than a reference to key resources) was provided on project-specific data collection and estimation methods to support the evaluation measures.

As the next logical work task, it is recommended that the research team work with TxDOT staff to apply and test the evaluation framework and associated procedures in actual ITS deployments occurring statewide. The recommended field application and testing will:

- ensure that the ITS evaluation framework described in this report is sound, comprehensive, and implementable;

- provide model examples that show how to develop detailed evaluation and data collection plans from a framework given specific deployment and implementation details; and

- enable the research team to work cooperatively with TxDOT headquarters and district staff to develop refined estimates of ITS benefits and impacts in Texas.

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