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16. Abstract

The purpose of this report is to summarize the reported benefits of deployed intelligent transportation systems (ITS) and the evaluation methods used to quantify these ITS benefits. A better understanding of the actual or expected benefits of ITS will allow TxDOT to make prudent ITS deployment and operating decisions. The authors present several evaluation frameworks that have been used to evaluate and quantify ITS benefits. Many of these frameworks are based on the five primary ITS goals (e.g. system efficiency / capacity, mobility, safety, environmental impacts, and economic productivity) identified in the National ITS Architecture. The authors concluded that the existing National ITS Architecture framework could serve as the basis for TxDOT's ITS evaluation methodology, with some adaptation for TxDOT's statewide goals, deployment strategy, and other considerations.

This report also provides a synthesis of the reported benefits for the priority user services identified in TxDOT's ITS Deployment Strategy. The authors found that reported benefits for similar ITS user services ranged widely (e.g., reductions in travel time ranged from 7 to 48 percent for ramp metering), presumably due to different pre-existing traffic conditions and ITS implementation details. The wide range in reported ITS benefits without accompanying data on pre-existing conditions made it difficult for the research team to accurately predict expected ITS benefits in Texas. The authors concluded that a careful re-examination of selected ITS evaluations may be necessary. The authors also recommend the development of an evaluation plan that could be used by TxDOT and the research team to fill gaps in existing ITS benefits knowledge.

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ITS BENEFITS: REVIEW OF EVALUATION METHODS AND REPORTED BENEFITS

by

Shawn Turner, P.E.
Assistant Research Engineer
Texas Transportation Institute

Wm. R. Stockton, P.E.
Research Engineer
Texas Transportation Institute

Scott James
Graduate Research Assistant
Center for Transportation Research

Troy Rother
Graduate Research Assistant
Texas Transportation Institute

and

C. Michael Walton, P.E.
Ernest H. Cockrell Centennial Chair in Engineering
Center for Transportation Research

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

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SUMMARY

Intelligent transportation systems (ITS) applications represent a significant opportunity to improve the efficiency and safety of the surface transportation system in Texas. These applications primarily improve the operation of a transportation system by either performing a function quicker or more reliably, or by providing a service that was not previously available. In so doing, ITS provides for improved mobility of people and goods on the existing surface systems, and they offer the potential for substantial savings in future construction, particularly of highways.

The biggest challenge to the professional and the traveler is in recognizing and appreciating the benefits that ITS can provide. This recognition is difficult because efficient operation of the highway system in particular is assumed, rather than understood. It is often assumed that, if a highway is properly designed and built, the traveling public will make safe and efficient use of it. However, failure to recognize the importance of investing in operations often results in expensive new roadway construction to deal with inefficiently managed travel demand.

This report is the first in a series to document for the Texas Department of Transportation the benefits of intelligent transportation systems. This initial effort takes a look at reported benefits from around the nation and draws some preliminary conclusions — both about the type and magnitude of benefits and about the techniques for measuring benefits and evaluating projects.

The U.S. DOT has published numerous reports that summarize the reported benefits of ITS. These reports provide a basic inventory of ITS benefits, and illustrate that there is a wide range in the reported magnitudes of benefits. While the studies conducted at the national level clearly demonstrate the value of ITS systems, they present the user with two principal problems. First, very little information has been provided in the DOT's ITS benefit inventories as to the pre-existing conditions or implementation details that have obviously impacted the magnitude of reported benefits. Second, benefits inventories to date typically have not provided critical review of reported benefits information. This report attempted to synthesize and review these reported benefit estimates, yet there are insufficient details in most of these benefits inventories to critically review reported ITS benefits.

Shortcomings notwithstanding, the experience documented in previous assessments is compelling. The preponderance of evidence is that prudently deployed ITS applications are having a significant impact on users and on the transportation systems affected. In the most recent comprehensive survey of benefits, Mitretek has made some significant findings in their research for the U.S. DOT. In some of their key measures, they found that certain ITS applications:

- reduced crash rates by an estimated 20 to 50 percent;

- reduced travel times on urban freeways and arterial streets by 8 to 48 percent; and
- improved the throughput, or vehicle capacity, by 8 to 32 percent.

Other evaluations conducted in Texas found that travelers on freeway systems in Houston, San Antonio and Fort Worth were saving hundreds of thousands of hours annually. In addition, there were significant air quality and emergency management benefits to accompany the benefits in reduced delay. Critically documenting these types of benefits and providing TxDOT with realistic estimates of problem-solving potential is the purpose of this research.

Based upon this first year of analysis, the research team concluded the following:

When properly implemented, ITS has the capability to deliver significant benefits to the traveling public and society as a whole. The magnitude of benefits achievable through ITS, though, has been shown to vary significantly between different regional ITS deployments. The researchers have concluded that this wide range of benefits is likely due to different pre-existing traffic/transportation system characteristics, implementation details, and/or benefit evaluation methods. Most ITS benefits documentation has provided very little detail on these critical factors that essentially determine the likely magnitude of benefits. In some sense, most ITS benefits documentation has been directed at answering the question "Should we deploy ITS?" instead of the more important question "How do we best deploy ITS to be an effective transportation improvement?"

Rigorous evaluation of existing ITS deployments plays a key role in gathering information for ITS deployment planning and implementation. Unfortunately, however, rigorous ITS evaluations have often not been a priority in many ITS deployment activities. It appears that many ITS evaluations have been conducted to justify expenditures, as opposed to understanding why and under what conditions benefits occur. In other cases, limited time and/or resources are devoted to ITS evaluation (often as an afterthought), and many layers of estimations and assumptions are used to replace sound empirical data in ITS benefits analyses. There is no doubt that ITS evaluation can be difficult for numerous reasons (e.g., difficulty of collecting adequate "before" data, isolating variables that affect measured changes, etc.); therefore, the scope of ITS evaluations should be commensurate with the value of the benefits information in making ITS deployment decisions.

The U.S. DOT is leading efforts aimed at improving the rigor and structure of ITS evaluations, the impact of which should likely be obvious in the near future. The "Performance and Benefits Summary" of the National ITS Architecture provides a relatively straightforward framework by which to evaluate ITS deployment based upon six national ITS goals. The U.S. DOT has put forth significant efforts in developing plans for and evaluating ITS deployment at the four Metropolitan Model Deployment Initiative (MMDI) sites. In addition, it has been rumored that the U.S. DOT is attempting to improve their annual ITS benefit inventories by providing more critical review and removing obsolete benefits information.

Based upon these conclusions, the research team recommends the following:

Continue to concentrate on how best to deploy ITS as an effective transportation improvement. ITS will likely be an element of many urban transportation systems 15 to 20 years from now. TxDOT should continue to focus its energies on understanding what user services and implementation details provide the most cost-effective transportation improvements. Similarly, TxDOT should also recognize that the appropriate operation and maintenance of existing ITS is necessary to achieve (as well as sustain) ongoing benefits from ITS.

Carefully consider any efforts to monetize all ITS benefits. The research team reviewed several economic benefit analyses that reduced all ITS measures of effectiveness to a single dollar benefit amount. Although non-technical audiences or decision-makers may prefer or even demand that ITS benefits be described in purely monetary terms, there appears to be a lack of credibility for such analyses among the transportation profession. Because of this lack of credibility, the researchers recommend that ITS benefit analyses concentrate on basic measures of effectiveness. These measures can be monetized (with appropriate sensitivity analyses) when required by non-technical audiences, but only to indicate the general magnitude or range of anticipated monetary benefits. The corollary to this suggestion is: **Do not discard a potential application simply because its benefits cannot be readily monetized.**

Avoid the temptation to be overly precise in estimating benefits. Most benefits cannot at this juncture be estimated more closely than two or three significant digits. Even though a calculator may be capable of ten or more significant digits, the underlying estimates and assumptions do not allow that level of precision.

Investigate adaptation of the National ITS Architecture benefits framework. The National ITS Architecture provides a framework by which to quantify ITS benefits. This benefits framework should be investigated by the research team, and elements specific to ITS deployment in Texas should be added. The research team should also develop additional detail for quantifying the benefit metrics in this framework.

Re-examine existing Texas data and develop evaluation plans. The existing data from Texas ITS deployments should be re-examined to determine its suitability for future application of the benefits analysis principles articulated in the National ITS Architecture and the Volpe Center benefits framework research. To the degree that the data are available, supplemental analyses would be conducted. An evaluation plan spanning the next several years of research should be developed to obtain, collect, or acquire ITS benefits data where significant gaps in reported ITS benefits exist.

CHAPTER 1—INTRODUCTION

Intelligent transportation systems (ITS) offer a very broad array of benefits to virtually all users and operators of surface transportation systems. Because of the breadth and diversity of the potential, it is essential to have a meaningful framework for evaluating and discussing benefits. This introductory chapter describes work to date at the national level to develop this meaningful framework. That discussion is followed by a recap of TxDOT's *ITS Deployment Strategy*, which highlights the key areas of emphasis for TxDOT over the near term.

OVERVIEW OF NATIONAL ITS PROGRAM

Extensive work has been done at the national level to provide a logical structure to ITS. This structure, termed the National ITS Architecture, describes the physical and logical interaction among: a) ITS components, b) the surface transportation system, and c) users of both. This framework relates the goals, benefits, products, and services of ITS together in a manner that allows users of the Architecture to understand how ITS can best meet stakeholder needs.

Because of the breadth of ITS, understanding the relationships among goals, users services, service bundles, market packages, etc. can be challenging. Figure 1 is an illustration from the National ITS Architecture documents (1) that attempts to show how ITS functions and stakeholders are interrelated.

The complex nature of ITS fosters the temptation to jump quickly to a specific service or anticipated benefit as a shortcut to satisfying an immediate need for information or application. In some respects, intelligent transportation systems are like the human body–the parts and functions are so interrelated that action taken in one area often impacts another. Therefore it is crucial to examine ITS products and services according to a deliberate, systematic approach, so that future discussions of specific applications are couched in the proper overall context.

The ITS benefits discussion will be most productive if it is preceded by a recap of the underlying principles, presented in a logical sequence. The Goals of ITS describe the intended purpose or outcome of intelligent transportation systems. The Objectives identify what kinds of measurable changes might be achieved. These objectives are very important in that they are a forerunner of the benefits measurements that will be discussed in detail later.

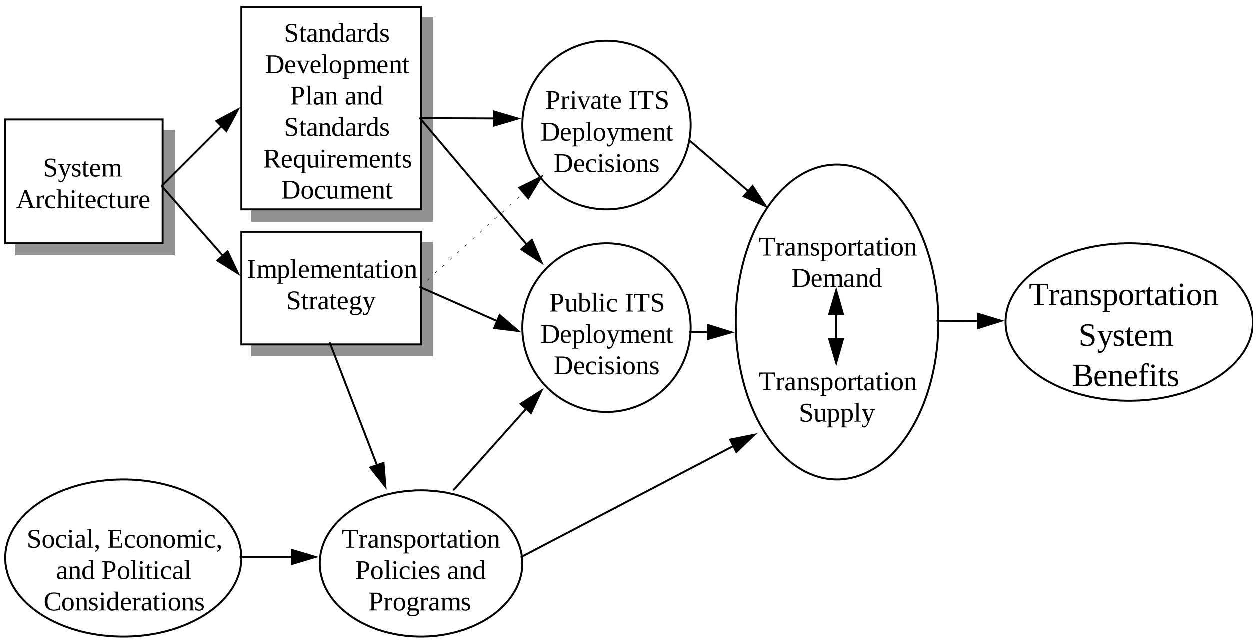

Figure 1. The Relationship of ITS System Architecture to the Benefits
(Source: U.S. DOT, (1), p. 37)

The next discussion is of the User Services themselves. These services describe the kinds of improvements that are anticipated by deployed ITS applications. The Market Packages describe the actual products and services that will be deployed in order to achieve the improvements associated with the User Services. And, finally, there is a table that will relate the deployed Market Packages back to the original Goals.

ITS Goals

The national ITS program is focused on six goals, five of which are germane to the TxDOT program (2). Those five goals are to:

- *Increase operational efficiency and capacity of the transportation system.*
- *Enhance personal mobility and the convenience and comfort of the transportation system.*
- *Improve the safety of the nation's transportation system.*
- *Reduce energy consumption and environmental costs.*
- *Enhance the present and future economic productivity of individuals, organizations, and the economy as a whole.*

ITS Development Objectives

The objectives articulated in Table 1 outline the specific, measurable improvements that can be expected for each of the five major ITS goals. These objectives will lead to the initial layer of measurements (or "metrics") that can be used to quantitatively estimate benefits.

Table 1. ITS Development Objectives

Increase operational efficiency and capacity of the transportation system • Increase operational efficiency • Increase speeds and reduce stops • Reduce delay at intermodal transfer points • Reduce operating costs of the infrastructure • Increase private vehicle occupancy and transit usage • Reduce private vehicle and transit operating costs • Facilitate fare collection and fare reduction/equity strategies • Reduce freight operating costs and increase freight throughput consumed

Enhance personal mobility, convenience, and comfort of the transportation system
• Increase personal travel opportunities
• Increase awareness, and ease of use of transit and ridesharing
• Decrease personal costs of travel including:
    • Travel time, travel time reliability and travel cost
    • Comfort, stress, fatigue, and confusion
    • Safety and personal security
• Increase sense of control over one's own life from predictable system operation
• Decrease cost of freight movement to shippers, including:
    • More reliable "just-in-time" delivery
    • Travel time and cost
    • Driver fatigue and stress
    • Cargo security
    • Safety (e.g., from tracking hazardous material)
    • Transaction costs

Improve the safety of the nation's transportation system • Increase personal security • Reduce number and severity (cost) of accidents, and vehicle thefts • Reduce fatalities
Reduce energy consumption and environmental costs • Reduce vehicle emissions due to congestion and fuel consumption due to congestion • Reduce noise pollution • Reduce neighborhood traffic intrusiveness
Enhance the present and future economic productivity of individuals, organizations, and the economy as a whole • Increase sharing of incident/congestion information • Reduce information-gathering costs • Increase coordination/integration of network operation, management, and investment • Improve ability to evolve with changes in system performance requirements and technology

Source: U.S. DOT, (2)

ITS User Services

The initial organization of ITS products and services centered on 29 defined User Services. Since then the Rail-Highway Intersection has been added, and most recently, the Archived Data User Service as the 31st user service. Table 2 lists the user services by the "bundle" to which they most logically belong.

Table 2. ITS User Services

User Services Bundle	**User Services**
Travel and Transportation Management	• En-Route Driver Information • Route Guidance • Traveler Services Information • Traffic Control • Incident Management • Emissions Testing and Mitigation • Demand Management and Operations • Pre-Trip Travel Information • Ride Matching and Reservation • Highway Rail Intersection
Public Transportation Operations	• Public Transportation Management • En-Route Transit Information • Personalized Public Transit • Public Travel Security
Electronic Payment	• Electronic Payment Services
Commercial Vehicle Operations	• Commercial Vehicle Electronic Clearance • Automated Roadside Safety Inspection • On-Board Safety Monitoring • Commercial Vehicle Administration Processes • Hazardous Materials Incident Response • Freight Mobility
Emergency Management	• Emergency Notification and Personal Security • Emergency Vehicle Management
Advanced Vehicle Control and Safety Systems	• Longitudinal Collision Avoidance • Lateral Collision Avoidance • Intersection Collision Avoidance • Vision Enhancement for Crash Avoidance • Safety Readiness • Pre-Crash Restraint Deployment • Automated Highway System

Source: U.S. DOT, (2), p. 24

ITS Market Packages

In reality, ITS applications will be deployed in "packages" that will serve the needs of the users in a particular setting. Table 3 shows how the defined User Services would be provided by Market Packages of equipment and software as they are likely to be deployed. As evident in the table, numerous market packages may contribute to any of the user services. Likewise, each market package may provide benefits in more than one user service. It is important to recognize these overlaps to assure that ITS evaluations, even those qualitative in nature, include appropriate benefits. It is also important to point out that over time the matrix will evolve, increasing the coverage of services addressed by various market packages.

Relationship of Market Packages to ITS System Goals

Early work by the Joint Architecture Team focused on qualitatively identifying the benefits of the various market packages. Table 4 shows the results of that effort. As indicated in the key, the Team also attempted to rate the probable benefits according to the expected magnitude of the benefits of a particular package in addressing a specific goal. For example, the market package "Interactive Traveler Information" is expected to have a moderate impact on the goal of improving system efficiency, a high impact on improving personal mobility, and a low impact on improving the environment. These qualitative assessments will aid in identifying priorities for action.

Table 3. Mapping of Market Packages to User Services

	User Services																												
Market Package	1.1 - Pre - Trip Travel Information	1.2 - En - Route Driver Information	1.3 - Route Guidance	1.4 - Ride Matching and Reservation	1.5 - Traveler Services Information	1.6 - Traffic Control	1.7 - Incident Management	1.8 - Travel Demand Management	1.9 - Emissions Testing and Mitigation	2.1 - Public Transit Management	2.2 - En - Route Transit Information	2.3 - Personalized Public Transit	2.4 - Public Travel Security	3.1 - Electronic Payment Services	4.1 - Commercial Vehicle Electronic Clearance	4.2 - Automated Roadside Safety Inspection	4.3 - On - Board Safety Monitoring	4.4 - Commercial Vehicle Administrative Processes	4.5 - Hazardous Material Incident Response	4.6 - Commercial Fleet Management	5.1 - Emergency Notification and Personal Security	5.2 - Emergency Vehicle Management	6.1 - Longitudinal Collision Avoidance	6.2 - Lateral Collision Avoidance	6.3 - Intersection Collision Avoidance	6.4 - Vision Enhancement for Crash Avoidance	6.5 - Safety Readiness	6.6 - Pre - Crash Restraint Deployment	6.7 - Automated Vehicle Operation
Network Surveillance						✓																							
Probe Surveillance						✓																							
Surface Street Control						✓	✓																						
Freeway Control						✓	✓	✓																					
HOV and Reversible Lane Management						✓		✓																					
Traffic Information Dissemination						✓																							
Regional Traffic Control						✓																							
Incident Management System							✓																						
Traffic Network Performance Evaluation						✓		✓																					
Dynamic Toll/Parking Fee Management								✓						✓															
Emissions and Environmental Hazards									✓																				
Virtual TMC and Smart Probe Data		✓				✓	✓																						
Transit Vehicle Tracking										✓	✓	✓	✓																
Transit Fixed-Route Operations										✓	✓																		
Demand Response Transit Operations										✓	✓	✓																	
Transit Passenger and Fare Management											✓			✓															
Transit Security										✓			✓																
Transit Maintenance										✓																			
Multi-modal Coordination						✓		✓		✓																			
Broadcast Traveler Information	✓	✓									✓																		
Interactive Traveler Information	✓	✓									✓	✓		✓															
Autonomous Route Guidance		✓	✓																										
Dynamic Route Guidance		✓	✓																										
ISP Based Route Guidance	✓	✓	✓											✓															
Integrated Transportation Mgmt/Route		✓	✓											✓															
Yellow Pages and Reservation	✓	✓			✓									✓															
Dynamic Ridesharing	✓	✓		✓							✓	✓		✓															
In Vehicle Signing		✓				✓																							
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																													✓
Fleet Administration																				✓									
Freight Administration																			✓										
Electronic Clearance															✓			✓											
Electronic Clearance Enrollment				✓											✓			✓											
International Border Electronic Clearance															✓			✓											
Weigh-In-Motion															✓														
Roadside CVO Safety																✓													
On-board CVO Safety																	✓												
CVO Fleet Maintenance										✓							✓			✓									
HAZMAT Management							✓												✓	✓									
Emergency Response																						✓							
Emergency Routing																						✓							
Mayday Support												✓									✓	✓							
ITS Planning										✓																			

Source: U.S. DOT, (1), p. 10

Table 4. Benefits of Market Packages for Achieving ITS System Goals

	Market Packages	Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity
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		*	*		*

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

Table 4. Benefits of Market Packages for Achieving ITS System Goals (continued)

	Market Packages	Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity
		ITS System Goals				
CVO	Fleet Administration		***			***
	Freight Administration		***			***
	Electronic Clearance	**	***			***
	CV Administrative Processes					**
	International Border Electronic Clearance	**	***			***
	Weigh-In-Motion	**	***			***
	CVO Fleet Maintenance	0			**	**
	HAZMAT Management	0			**	**
	Roadside CVO Safety		**		**	**
	On-board CVO Safety				***	**
AVSS	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	***	***		***	
EM	Emergency Response			*	***	**
	Emergency Routing			*	***	**
	Mayday Support				***	*
ITS	ITS Planning	**	**	**	**	**

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

Source: U.S. DOT, (1), pp. 9-10

REVIEW OF TXDOT ITS DEPLOYMENT STRATEGY

TxDOT's guiding policy in ITS deployment is the *ITS Deployment Strategy* (3), adopted by the Texas Transportation Commission in May 1996. That document, developed under the guidance of senior managers deploying ITS and approved by the Standing ITS Committee, outlines the near-term focus for TxDOT. Recognizing that TxDOT could not practically embrace all of ITS simultaneously, the Strategy document identifies key areas where TxDOT would take a lead role or a critical support role.

Table 5 is the summary table from the Deployment Strategy. The areas for a lead role were those where TxDOT is already primarily responsible for implementation. The *ITS Deployment Strategy* recommends that TxDOT take a lead role in the following user services:

- traffic control;
- en-route driver information;
- incident management; and
- rail-highway grade crossing operations.

According to the *Strategy*, TxDOT will play an alternate lead role in:

- pre-trip travel information;
- commercial vehicle electronic clearance; and
- commercial vehicle administrative processes.

The *Strategy* recommends that TxDOT support other agencies in the following:

- smart emergency systems;
- travel demand management;
- public transportation management;
- en-route transit information; and
- public travel security.

Table 5. Recommended Early Emphasis Areas

User Service	TxDOT Near-Term Role	Deployment Roles [a]			
		TxDOT	City/County	Transit Authority	Private
Traffic Control	Deployment (state roads)	◆	❖	❍	
En-Route Driver Information	Deployment (also facilitate long-term private role)	◆	❖	❍	Info Providers?
Incident Management	Leadership of local partners + Deployment (state roads)	◆	❖	❖	Cellular Providers?
Rail-Highway Grade Crossing Operations	Exploration + Deployment	◆			Railroads
Smart Emergency Systems	Coordination + Deployment	❍	◆		
Pre-Trip Travel Information	Leadership (establish policy framework for private sector delivery) + Coordination	❖	◆	◆	Info Providers?
Travel Demand Management	Coordination with local entities	❍	◆	◆	
Public Transportation Management	Coordination with transit authorities	❍	❍	◆	
En-Route Transit Information	Provide access to real-time system condition data	❍	❍	◆	
Public Travel Security	Coordination of video capabilities with transit authorities	❍	❍	◆	
Commercial Vehicle Electronic Clearance	Coordination with federal, state, and motor carriers	❖	❍		◆ - Motor Carriers
Commercial Vehicle Administrative Processes	Coordination with motor carriers	❖	❍		◆ - Motor Carriers

Note: [a] ◆ = Typical Lead Role; ❖ = Alternate Lead Role; ❍ = Typical Support Role
Source: TxDOT, (3), p. ix

CHAPTER 2—ITS EVALUATION METHODOLOGIES

This chapter contains a discussion of existing and proposed evaluation methodologies for intelligent transportation systems (ITS). The chapter starts by explaining why we need to evaluate ITS. The state-of-the-practice in ITS evaluation is presented next, with a brief discussion of TxDOT's project evaluation methods as well as the methods used to evaluate ITS projects in Texas. The chapter also summarizes the ITS evaluation framework from the National ITS Architecture, as well as summarizing recommended ITS evaluation practices detailed in recent literature. The chapter concludes with findings related to ITS evaluation methodologies.

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 critiquing existing and proposed evaluation methods. Transportation professionals evaluate ITS to:

- **understand the impacts** - ITS is evaluated to better understand its impact and effect on transportation systems and users, as well as its social, economic, and environmental impacts.

- **quantify the benefits** - Recent trends require federal, state, and local government to measure its performance and quantify the benefits of public/private sector investments (e.g., "return on taxpayer's money").

- **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. Benefit information 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 correct, improve, or "fine-tune" system operation or design.

STATE-OF-THE-PRACTICE IN ITS EVALUATIONS

Existing TxDOT Transportation and ITS Project Evaluation Methods

TxDOT currently uses several different techniques or methods to evaluate the impacts and operational characteristics of roadways. Some of these evaluations are oriented towards operational efficiency and consist of capacity analyses based on the *Highway Capacity Manual* (HCM) (4). Most HCM analyses use traffic volumes, roadway geometric characteristics, and signal operation parameters (arterial streets only) to calculate a level of service (LOS). Many of the HCM analyses, however, do not capture the full benefits of ITS because of the capacity-based approach. Furthermore, most HCM analyses are oriented toward operational analyses and are not practical to use for planning analyses because of the many required input parameters. In lieu of HCM analyses, other operational evaluations incorporate simple measures of effectiveness, such as reduction in congestion (e.g., vehicle-hours of delay) or safety improvements (e.g, crash rate). Other measures of effectiveness sometimes included in traffic operations computer models include fuel consumption and mobile source emissions.

Different techniques are used in the transportation planning process to prioritize roadway projects in TxDOT's 10-year funding plan, the Unified Transportation Program (UTP) (5). The UTP consists of 37 funding categories representing various TxDOT functions, such as new construction, reconstruction, maintenance, safety, enhancements, traffic management, congestion mitigation and air quality, etc. Of the 37 funding categories, 20 categories are focused on providing mobility. Within several of the funding categories related to mobility (e.g., 3A-NHS Mobility, 3B-NHS Texas Trunk System), projects are ranked according to the cost-effectiveness index, which is a ratio of the project cost and traffic congestion level (Equation 1). Within Category 3D-NHS Traffic Management Systems, projects are ranked by the traffic management index, a ratio of project cost to congestion and accident reduction potential (see the following section for more discussion). Within other categories, projects are ranked by factors such as population, cost-benefit considerations, and roadway system extent and travel.

$$Cost\text{-}Effectiveness\ Index = \frac{Project\ Cost}{\begin{array}{c}Congested\ Vehicle\text{-}Miles\ of\ Travel\\(VMT\ below\ LOS\ C)\end{array}} \tag{1}$$

Revised Traffic Management Index

In 1994, the Texas Transportation Institute (TTI) developed a revised traffic management index (TMI) (6) that could be used to rank and prioritize traffic management projects in Category 3D of TxDOT's UTP. The revised TMI combined into a single index the following factors (Equation 2):

- project cost;
- recurring congestion delay savings;
- non-recurring congestion delay savings; and
- accident cost savings.

$$Revised\ TMI = \frac{Project\ Cost}{(R\ Factor)\begin{matrix}Recurring\\Delay\ Cost\end{matrix} + (NR\ Factor)\begin{matrix}Non-Recurring\\Delay\ Cost\end{matrix} + (A\ Factor)\begin{matrix}Accident\\Cost\end{matrix}} \qquad (2)$$

In the revised TMI, congestion costs are estimated from average daily traffic (ADT) volumes per lane and the project length. Congestion and accident reduction factors were estimated from available literature and anecdotal experience (Table 6). As an example, the revised TMI was used to prioritize different types of traffic management strategies, such as freeway traffic management systems, changeable message signs, lane control signals, and signal system interconnects.

Table 6. Revised TMI Reduction Factors

Traffic Management Strategy	Reduction Factor		
	Recurring Delay	**Non-Recurring Delay**	**Accidents**
Traffic Management System	0.30	0.60	0.50
Traffic Management System Individual Components:			
Ramp Metering	0.20	0.15	0.20
Lane Control Signals	0.05	0.10	0.10
Changeable Message Signs	0.05	0.15	0.05
Closed Circuit TV	0.00	0.10	0.05
Loop Detectors	0.00	0.05	0.05
Communication	0.00	0.05	0.05
Isolated Ramp Metering	0.15	0.10	0.20
Motorist Information (includes highway advisory radio, cellular communications)	0.00	0.10	0.10
Motorist Assistance Patrol	0.00	0.20	0.20
Signal System Improvements	0.30	0.20	0.20

Source: (6), p. 6

ITS Evaluations in Texas

Several ITS evaluations have been performed in the large urban areas of Texas, including Houston (TranStar), San Antonio (TransGuide), and Fort Worth (TransVision). Other estimates of ITS benefits have also been calculated in ITS planning studies in Dallas.

TranStar, Houston

Annual evaluations of Houston's TranStar center (a.k.a. Greater Houston Traffic and Emergency Management Center) were performed by the Parsons Transportation Group and TTI in 1997 (7) and by TTI in 1998 (8). The TranStar center officially began operation in April 1996, so the 1997 evaluation was performed for the latter half of 1996, whereas the 1998 evaluation was conducted for calendar year 1997.

The first annual evaluation in 1997 focused on only two ITS components in the Houston area: incident management and ramp metering (referred to locally as "flow signals"). The primary measures of effectiveness used in this evaluation were **annual delay savings** and the **dollar value of delay savings**.

The second annual evaluation in 1998 focused on several components of ITS deployment: the transportation management center itself, traveler information, incident management, ramp metering, and traffic signal systems. The primary measures of effectiveness used are very similar to the previous evaluation and include **annual delay savings, dollar value of delay savings, and benefit-to-cost ratio**. Other secondary measures that were estimated include reduction in fuel consumption and emissions. The manner in which these measures were calculated in this evaluation, however, are distinctly different from the previous evaluation. In this most recent evaluation, TranStar agency managers were asked to set goals for reducing congestion, then estimate the progress toward these goals over the past year.

Another small-scale study of ramp metering in Houston conducted by TxDOT and TTI used **reduction in average travel time** and **increases in average speed** to measure the benefits of ramp metering (9). This study used travel time data readily available through the region's automatic vehicle identification (AVI) traffic monitoring system.

TransGuide, San Antonio

TTI is conducting ongoing analyses of the TransGuide advanced transportation management system (ATMS) in San Antonio (10,11,12). A before-and-after study for Phase I of the system, which encompasses 42 km (26 mi) of freeway around the downtown, used several different analysis categories and measures of effectiveness (Table 7). Reductions and/or significant changes in these measures of effectiveness were then used to assess the overall effectiveness of Phase I of the TransGuide system. Before-and-after studies for Phase II of TransGuide expands the evaluation matrix of Phase I to include several new evaluation categories, including police operations, incident diversion characteristics, and system operator perceptions (Table 7).

Table 7. Measures of Effectiveness Used to Evaluate TransGuide in San Antonio

Category	Measures of Effectiveness	
	Phase I	**Phase II**
Safety Impacts	accident rate accident severity accident type	total accidents per vkt accident severity per vkt secondary accidents per vkt
Recurrent Congestion/Traffic Operations	travel delay fuel consumption vehicle emissions	travel time travel speed travel time reliability/variability freeway mainlane and ramp volumes
Incident Management	incident response time incident clearance time total incident duration	incident response time incident clearance time incident queue dissipation time
Driver Behavior, Understanding, and Utilization	comprehension of LCS and DMS compliance confidence and trust in system overall impression of the system	behavior during incidents perception of delays, system performance, and quality of information
VIA Transit Operations	schedule adherence/reliability	express route and paratransit operating stats (e.g., on-time performance)
San Antonio Police Operations	not evaluated	false alarm rate person- and vehicle-hours mobilized per incident crime statistics
Incident-Related Diversion Characteristics	not evaluated	traffic volumes at arterial diversion route intersections traffic volumes on diversion freeways
System Operator Perception	not evaluated	perception of TxDOT, SAPD, and VIA operators regarding system benefits and changes in job efficiency

Source: Texas Transportation Institute, San Antonio, Texas.

TransVision, Fort Worth

TxDOT staff in Fort Worth conducted analyses that estimate the benefits of incident management as conducted in the TransVision traffic management center (13). The primary measures of effectiveness used in the evaluation include **vehicle delay savings per incident, total delay savings, and annual dollar value of delay savings**. These measures were calculated by using historical traffic volumes in a computer model and assuming various incident characteristics (e.g., incident occurrence and clearance times, queue clearance time, number of lanes affected, etc.). The impact of incident management on secondary incidents was identified but not quantified.

Dallas ITS Early Deployment Plan

TTI staff in Dallas and Arlington developed the Dallas ITS Early Deployment Plan in cooperation with TxDOT and other regional transportation agencies. The proposed ITS deployment in Dallas was evaluated by using computer modeling and other prediction tools to estimate measures of effectiveness. The measures used to evaluate the proposed ITS deployment include **reduction in accidents, reduction in delay and fuel consumption costs, and a benefit-to-cost ratio**.

ITS Evaluations—ITS Program Plan and National ITS Architecture

The U.S. DOT and ITS America jointly developed the *National ITS Program Plan* (2), the purpose of which is to guide the development and deployment of ITS in the United States. The National ITS Program Plan presented six goals (five relevant goals shown here with further objectives) for the national ITS program:

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

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

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

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

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

In developing the National ITS Architecture, the U.S. Department of Transportation developed performance measures or metrics that are related to these six ITS goals (1). Table 8 presents a matrix 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" (14). These "few good measures" are as follows:

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

These few good measures have been tracked for the past several years by the ITS Joint Program Office and documented in an ongoing series of reports (14,15,16,17).

Table 8. 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, (1), p. 61

STATE-OF-THE-ART IN ITS EVALUATIONS

Evaluation Methods Similar to National ITS Architecture Framework

Many ITS evaluation frameworks and methodologies contained in recent literature closely parallel the goal-oriented evaluation approach suggested by the U.S. DOT and are shown in Table 8. Richeson and Underwood (18) discuss the benefits of ITS in relation to these five ITS goals, and document quantified benefits from several field operational tests. Rogova and Summers (19) also discuss ITS benefits analysis in relation to the five national ITS goals. Brand (20) presents ITS evaluation criteria that, although organized differently, relates to the basic five national ITS goals. Brand makes several distinctions, though, in discussing the ITS evaluation process. The paper stresses the importance of the following:

- Separation of the supply-side (operational efficiency) impacts from the demand-side response (increased output), which makes it possible to evaluate induced travel.

- Separation of ITS impacts by time frame of occurrence (i.e., short-, medium-, and long-term), which highlights certain fundamental correlations between the criteria and simplifies the evaluation process. Because different ITS impacts occur at different time frames after implementation, Brand suggests that the evaluation framework recognize the different time frames in which impacts occur to prevent the double-counting of benefits.

- Recognition of the affected or impacted groups, such as transportation system users (e.g., urban, rural, elderly, suburban, etc.), non-users, public sector operators, private sector operators, and private sector industry. The recognition of affected or impacted groups can be used in evaluation trade-offs.

Underwood and Gehring (21) present ITS evaluation techniques and discuss the challenges of evaluating ITS impacts to the public and private sectors. Table 9 illustrates important concepts that relate appropriate evaluation tools to potential impact categories. In this table, the impact categories are analogous to the national ITS goals as described earlier.

Table 9. Appropriateness of Evaluation Tools for ITS Impact Categories

Evaluation Tool	ITS Impact Categories						
	System Technical Performance	Safe and Efficient User Interface	Individual Driver Behavior and Impact	User Attitudes and Preferences	Traffic Behavior and Impacts	Environment and Energy Impacts	Institutional and Socioeconomic Impacts
Field Experiment	****	****	***	***	**	**	*
Field Quasi-Experiment	***	***	****	***	****	****	*
Surveys	*	**	**	****	*	*	***
Subject Debriefing	**	**	**	****	*	*	**
Cost Analysis	****	*	***	*	****	****	*
Extrapolate Impact Assessment	*	*	****	*	****	****	*
Narrative Case Studies	***	**	**	**	**	**	****

Note: **** = most appropriate; *** = often appropriate; ** = occasionally appropriate; * = least appropriate

Source: adapted from (21), p. 17

Tarry (22) describes an ITS evaluation framework developed in the U.K. that has been used to evaluate four separate ITS projects. The paper stresses the importance of a performance indicators framework that includes value-for-money indicators, as well as the potential for using data collected by the systems themselves as a means of conducting ITS evaluations. The evaluation framework was used to evaluate the following four projects:

- SCOOT adaptive signal control system in Aberdeen;
- dynamic message signs on the M40 in West Midlands;
- driver information system in Scotland; and
- accident reduction scheme in Yorkshire.

Table 10 illustrates the set of performance indicators used to evaluate the dynamic message signs. Similar evaluation categories were used to evaluate the other ITS projects.

Table 10. 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 VMS nodes • reduction in delays and extent of queuing • change in travel times 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 relative 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 other undesirable routes • number of accidents
Socio-Economic Analysis	• user cost-benefit analysis of network performance • impact on non-road users
Legal/Institutional Analysis	• legal/institutional conflicts
Public Acceptance Analysis	• user attitudes to VMS • non-user attitudes to VMS

Source: (22), p. 27

Economic Analyses of ITS Impacts

Several published research papers and ongoing research studies are focused on quantifying the short- and long-term economic impacts of ITS deployment. In general, this area of research is attempting to better estimate the economic impacts of ITS on the following:

- the private sector and their decision making;
- regional and national economies (i.e., employment, productivity, etc.); and
- technical innovation and competitiveness.

Zavergiu et al. (23) present an ITS benefit-cost framework that encompasses more than benefits accrued to transportation system users through congestion reduction and safety improvements. The authors suggest that ITS evaluations include four separate beneficiaries: individual transportation users, transportation infrastructure providers and managers, the community, and potential private investors/ITS technology providers. The authors also propose a hierarchy of benefits and costs that identifies and classifies benefits according to relevant costs: first order benefits, which are targeted to individual transportation users; second order benefits, applicable to transportation infrastructure providers and managers; and third order benefits, which directly impact the economy and the environment. The proposed ITS evaluation framework is applied to a real-world example, an automated vehicle identification (AVI) system for a Canadian border crossing.

Novak and McDonald (24) provide an overview of the potential macroeconomic impacts of ITS investment in the U.S. The macroeconomic impacts discussed in this paper include direct employment, economic multiplier, national productivity gains, technological spin-offs, and competitiveness. The authors discuss the difficulties of measuring these macroeconomic impacts because the core ITS infrastructure has not yet been deployed in most metropolitan areas. Further, the macroeconomic impacts involve complicated interrelationships between different sectors of the economy and between different economic effects.

TTI researchers with the ITS Research Center of Excellence (RCE) are also investigating the impacts of ITS in an effort parallel to this TxDOT-funded study. Preliminary research in this effort has identified the need to look beyond the traditional user benefits (e.g., vehicle delay, crash rate reduction) and consider non-user impacts. The researchers are basing their work on the national ITS goals, but are focusing on private sector impacts as well as qualitative impacts.

ITS research underway at the University of California at Berkeley is also examining the economic value of ITS projects. Preliminary research in this effort is focused on using benefit-cost analyses in ITS decision making, which requires that analysts be able to assign a monetary value to all of the impacts. This research effort also draws upon the five national ITS goals and distinguishes between three affected groups: transportation users, transportation agencies, and communities.

Findings Related to ITS Evaluation Methodologies

The following are the authors' findings related to ITS evaluation methodologies:

- **Several Existing Evaluation Methodologies -** The state-of-the-practice review revealed several evaluation methodologies, including those contained in the National ITS Architecture and endorsed by the ITS Joint Program Office, as well as other evaluation methodologies that include extensive lists of evaluation measures and benefits indicators. The authors also found several evaluation techniques traditionally used for highway economic analyses that could possibly be adapted for ITS.

- **ITS Evaluations in Texas -** There have been several ITS evaluations in Texas, focused mainly on those areas that have seen the most significant ITS deployment (e.g., Houston, San Antonio, Ft. Worth). There is no consistency in the evaluation methods used to estimate ITS benefits in these areas, although each evaluation does provide an estimated monetary value of ITS that can be easily referenced. With the exception of San Antonio, however, most of the ITS evaluations in Texas have only focused on a limited number of benefits (i.e., delay reduction).

- **Goals-Based ITS Evaluation Framework -** The framework of most evaluation plans was based upon the regional or local goals and objectives for ITS and transportation systems. The U.S. DOT has developed goals-based evaluation criteria (Table 8) for the six national goals for ITS and presents a list of metrics or indicators that can be used to measure progress toward these goals.

- **Appropriate Role of Economic Analyses -** The researchers identified another basic approach to evaluating ITS, which consisted of economic analyses which attempted to quantify the specific monetary value of all ITS impacts. These approaches typically report a single benefit-to-cost ratio for ITS deployments, but these analyses are based on many assumptions about monetary benefits. Several goals-based evaluation frameworks incorporate an economic analysis as one of many components of the overall evaluation, as opposed to an economic analysis as the framework.

- **Complexity of ITS Evaluations -** The research team found significant variance in the complexity of ITS evaluations. It was concluded that the desired 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.

- **Cost of ITS Evaluations -** The cost of ITS evaluation may also be a limiting factor in terms of complexity and sophistication. In some cases, 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.

CHAPTER 3—REPORTED BENEFITS OF ITS PROJECTS

The extensive interest in and deployment of intelligent transportation systems (ITS) nationwide has produced many estimates and projections of benefits. This chapter focuses on reported benefits from projects in Texas and the U.S. The ongoing ITS benefits reports from the ITS Joint Program Office (JPO) recognizes the following three types of benefit estimates (14):

- **Measured -** outcome results from field measurement of benefits through studies (the most compelling results)

- **Anecdotal -** estimates made by people directly involved in field projects (compelling, but less reliable than measured outcomes in terms of quantitative benefits estimates)

- **Projected -** results from analysis and simulation (useful tools for estimating impact when field measurements are not available) (14)

Estimates of ITS benefits included in this report should be assumed to be measured unless otherwise indicated. Because much of the deployment and full-scale evaluation of ITS products and services is ongoing, the accuracy and sample size of the evaluations are limited. Therefore, the primary caveat in this document is that the results have been reported by others. Where possible, the authors identify key limitations or cautions in using reported benefit estimates.

Since many benefit estimates were obtained from the JPO reports, the authors have attempted to reference the original source document as well as the relevant JPO report. The specific details of many reported ITS benefits are not available in the JPO reports and most original source documents were not publicly available. Because of these two factors, the authors were not able to critically review the evaluation methods and assumptions used to derive the reported ITS benefits in the JPO reports.

BENEFIT FLOW DIAGRAMS

The Joint Architecture Team established a logical flow of benefits associated with the range of ITS products and services, and detailed that work in the appendix to the Final Performance and Benefits Summary in the National ITS Architecture document (1). In the first level, market packages are shown with their logical relationship to benefit metrics (measurements of desired change). Once that relationship is established, the performance metrics can then be logically connected to the goals of ITS. Figure 2 shows schematically how this logical flow works. In other words, “x” package of ITS components will logically produce “y” benefits, which logically contribute to “z” transportation goal.

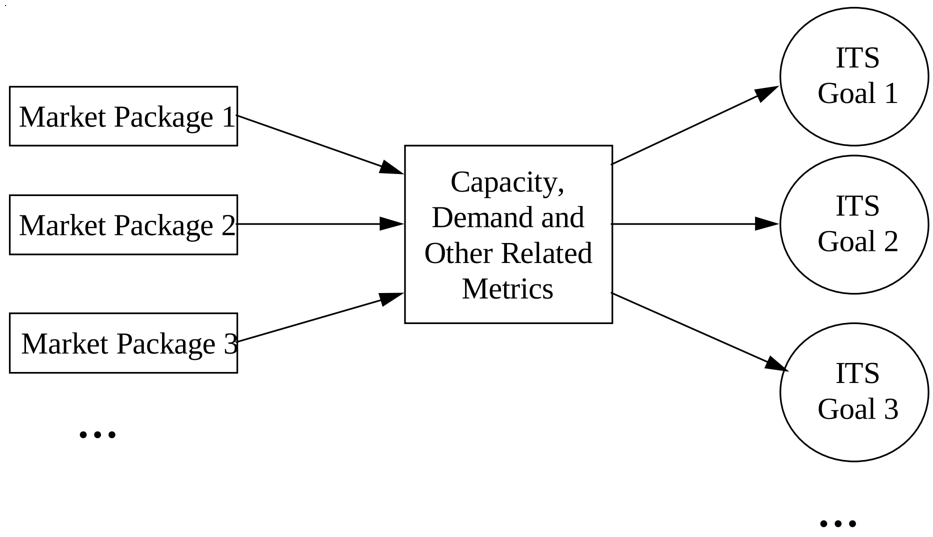

Figure 2. Benefits Flow Diagram Schematic
(Source: U.S. DOT, (1), p. 66)

These benefit flow diagrams allow the reader to understand the benefits that a particular ITS market package is likely to accomplish, and thus focus their planning in the most productive areas. Although the diagrams themselves do not provide any clue as to the magnitude of potential benefit, they provide a well-reasoned basis for initial decision making.

An example of interest to many traffic engineers would be the benefit flow diagrams associated with the market package, Surface Street Control. As we know from Table 3 in Chapter 1, this market package contributes to the Traffic Control and Incident Management User Services. The market package, Surface Street Control, would logically result in the following benefit metrics:

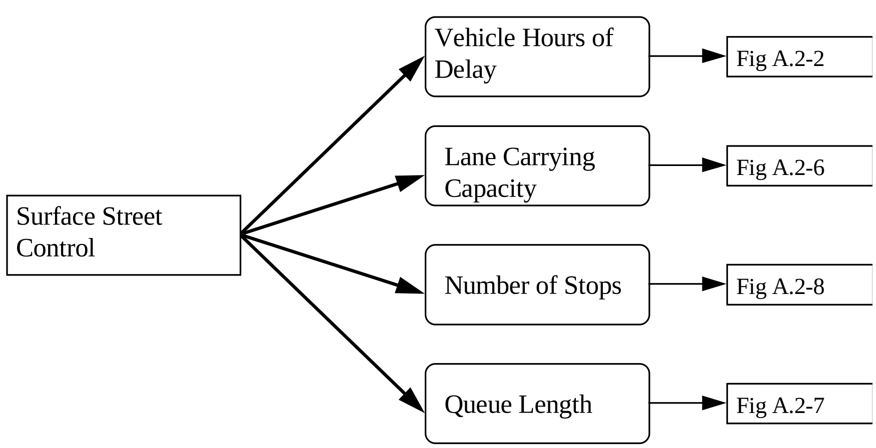

Figure 3. Metrics from Surface Street Control
(Source: U.S. DOT, (1), p. 114)

As mentioned previously, the architecture provides a logical connection between market packages and goals. Figure 3 shows the front half of that relationship (i.e., market package to performance metric). The boxes on the right refer to the connection between these performance metrics and the goals of ITS. An example of those relationships is shown below in Figure 4 for the metric “Number of Stops.”

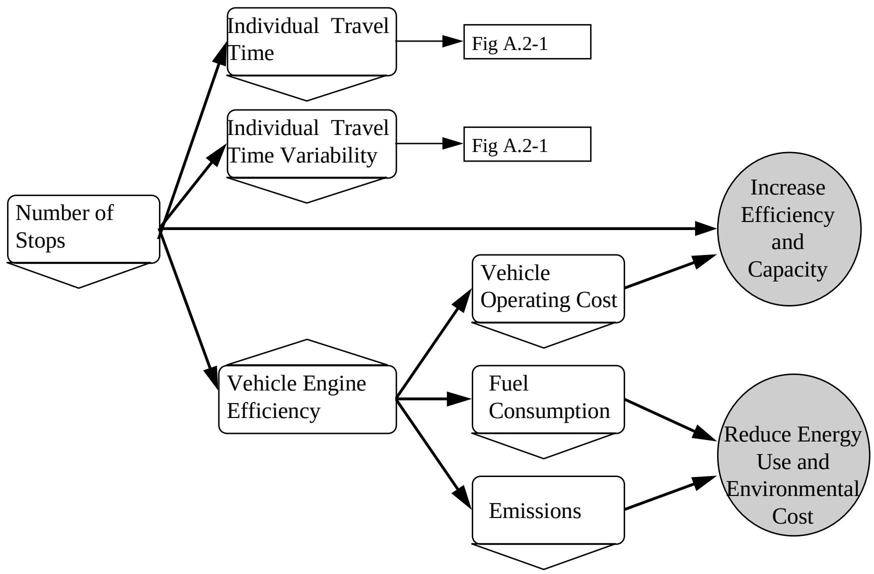

Figure 4. Metric of Number of Stops (Fig. A.2-8)
Source: U.S. DOT, (1), p. 135

So, the market package, Surface Street Control, produces a reduction in the number of stops, which leads to the two ITS goals of “Increase Efficiency and Capacity” and “Reduce Energy Use and Environmental Cost.” In addition, a reduction in the number of stops leads to reductions in individual travel time and travel time variability. Following that benefit diagram as indicated (Fig. A.2-1) would show that those two results contribute to the ITS Goal of “Increase Economic Productivity.”

Where meaningful in the following discussion, pertinent benefit flow diagrams will be shown. It is beyond the scope of this report to examine all of the benefit flow diagrams in detail. The reader is referred to Appendix A of the *Final Performance and Benefits Summary* for a detailed presentation of the benefit flow diagrams (1).

BENEFITS SUMMARY

The following sections describe the benefits reported for each of the major User Services that has been identified for TxDOT to take a leadership role. Using the *TxDOT ITS Deployment Strategy* (3), the following User Services have been identified for detailed benefits investigation:

- Traffic Control;
- En-Route Driver Information;
- Incident Management;
- Rail-Highway Grade Crossing Operations;
- Pre-Trip Travel Information;
- Commercial Vehicle Electronic Clearance; and
- Commercial Vehicle Administrative Processes.

Traffic Control Systems

Manages the movement of traffic on streets and highways.

The National ITS Program Plan (2) describes the traffic control user service as follows:

> "The traffic control user service provides for the integration and adaptive control of the freeway and surface street systems to improve the flow of traffic, give preference to public safety, transit or other high occupancy vehicles, and minimize congestion while maximizing the movement of people and goods. Through appropriate traffic controls, the service also promotes the safety of non-vehicular travelers, such as pedestrians and bicyclists. It requires advanced surveillance of traffic flows, analysis techniques for determining appropriate traffic signal and ramp metering controls, and communication of these controls to the roadside infrastructure. This service gathers data from the transportation system and organizes it into usable information to determine the optimum assignment of right-of-way to vehicles and pedestrians. The real-time traffic information collected by the traffic control services also provides the foundation for many other user services."

Traffic control user services typically consist of the following components:

- roadway surveillance using closed circuit television (CCTV) cameras;
- traffic condition monitoring using vehicle detection devices (e.g., inductance loop detectors, video, acoustic, infrared, radar, etc.) or probe vehicles (e.g., AVI or GPS-equipped vehicles);
- freeway ramp metering (fixed-time or traffic-adaptive);
- freeway lane control signals;

- arterial street signal control systems;
- signal preemption for priority vehicles (e.g., emergency, transit vehicles); and
- managed lanes for priority vehicles (e.g., high occupancy vehicles (HOV) or high occupancy and tolled (HOT)).

Generally, the benefits of traffic control systems are quantified using performance measures relating to system efficiency, travel mobility, and safety. Common examples include increased vehicle/person throughput, increased capacity, increased travel speeds, reductions in travel time, and reductions in fuel consumption and mobile source emissions. Figures 5 through 10 illustrate the benefit flow diagrams from the National ITS Architecture. Network and probe surveillance systems primarily feed data and information to other user services, whereas the benefits of surface street, freeway, and regional control can be quantified using vehicle-hours of delay, lane carrying capacity, number of stops, and queue length.

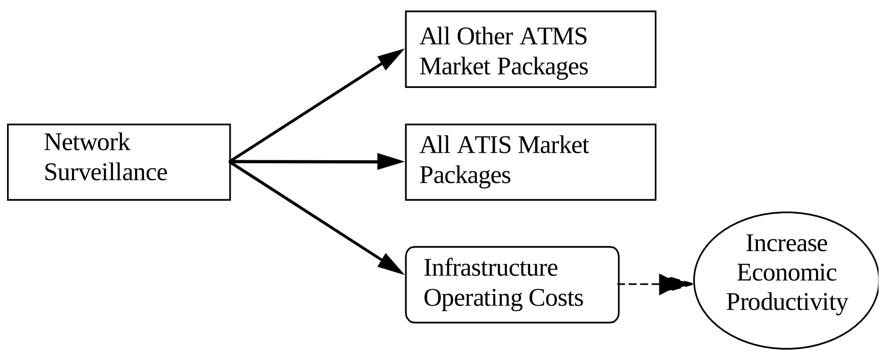

Figure 5. Metrics from Network Surveillance
Source: Adapted from U.S. DOT, (1), p. 114

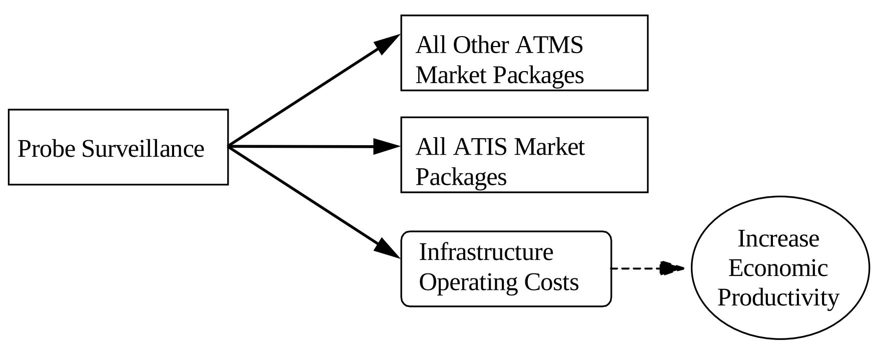

Figure 6. Metrics from Probe Vehicle Surveillance
Source: Adapted from U.S. DOT, (1), p. 114

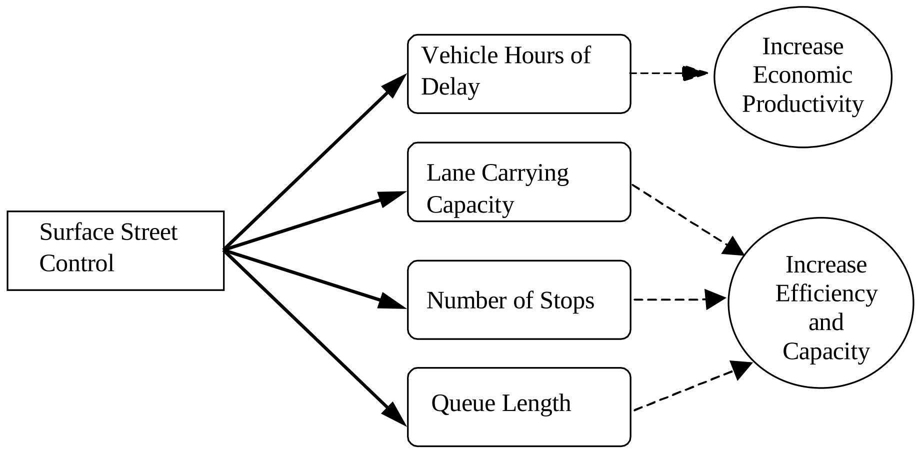

Figure 7. Metrics from Surface Street Control
Source: Adapted from U.S. DOT, (1), p. 114

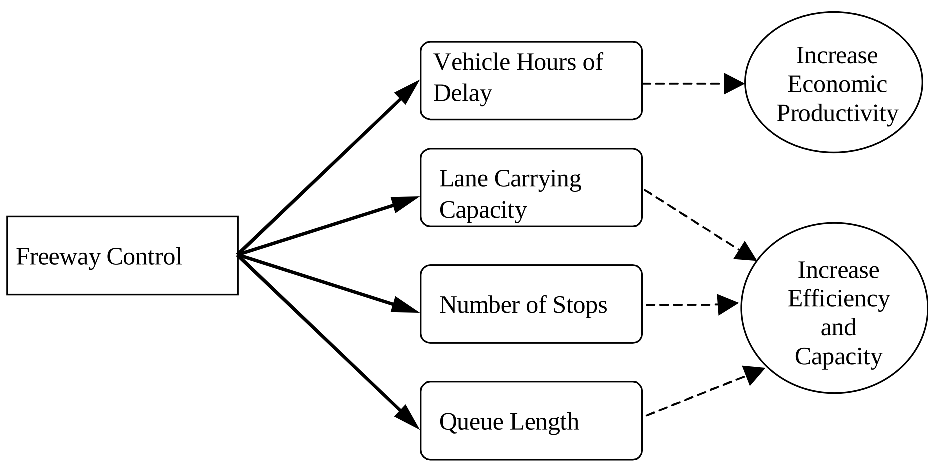

Figure 8. Metrics from Freeway Control
Source: Adapted from U.S. DOT, (1), p. 115

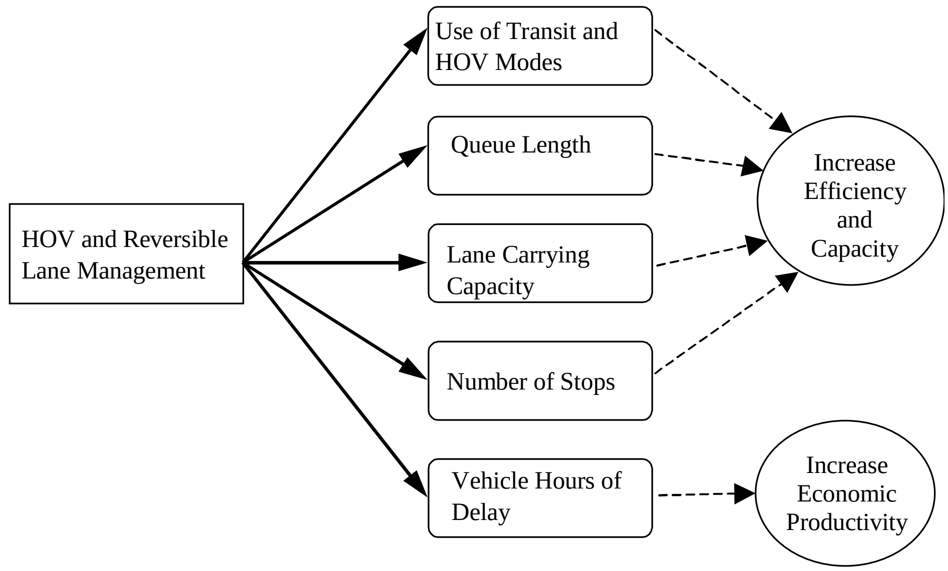

Figure 9. Metrics from HOV and Reversible Lane Management
Source: Adapted from U.S. DOT, (1), p. 115

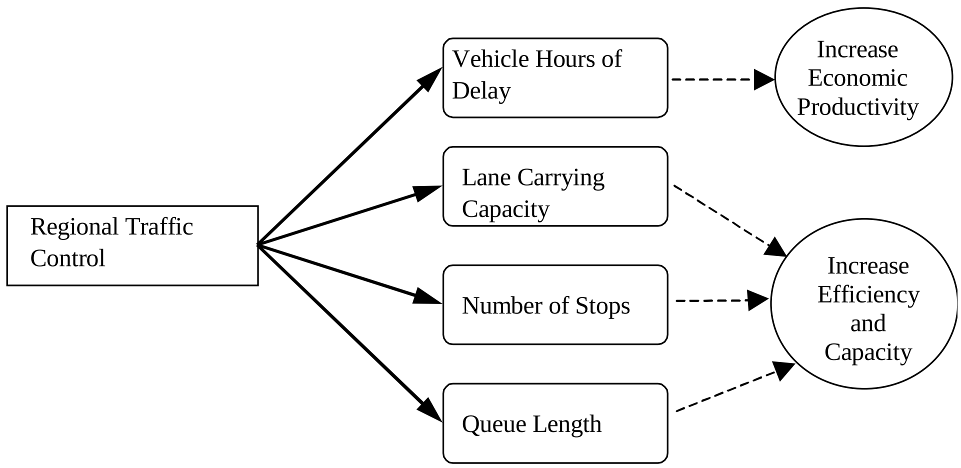

Figure 10. Metrics from Regional Traffic Control
Source: Adapted from U.S. DOT, (1), p. 116

Texas Experience

The documented benefits of traffic control systems in Texas is mainly focused on two locations: Houston and San Antonio (Table 11). The benefits of ramp metering have been documented in Houston, whereas the overall traffic control benefits of the TransGuide system were quantified in San Antonio. The study of the TransGuide system was only for Phase I, which includes 42 km (26 mi) of freeway around downtown San Antonio. TTI is currently collecting data for a before-and-after study of TransGuide Phase II.

The TransGuide Phase I evaluation compared response time to incidents before and after the implementation of a freeway surveillance and control system. The evaluation found a 20 percent improvement in response time, which was attributed to ITS. They used the FREFLO freeway simulation model to estimate delay and fuel savings, which they translated into an estimated annual dollar savings of $1.65 million.

A 1997 assessment of Houston's TranStar looked at the incident management benefits of the system. The analysis focused on the more severe incidents and was limited to the 6 a.m. to 7 p.m. time frame. The evaluators based total savings on a Houston Police Department estimate of a five-minute reduction in incident duration as a result of the improved capabilities of TranStar. That estimate is supported by an analysis of 1996 major incidents, which showed that incident duration had been reduced by 30 minutes subsequent to TranStar coming on line. Based on these estimates of incident duration, the annual benefits attributed to TranStar were savings of more than $8.4 M and more than 570,000 vehicle-hours of delay.

Table 11. Reported Benefits of Traffic Control Systems in Texas

ITS Component, Bundle, User Service, or System	Benefits Attributed to Traffic Control Functions	Comments
TransGuide Phase One, San Antonio (10,11,12) [traffic control functions include roadway surveillance, traffic condition monitoring, changeable message signs, and lane control signals]	• 16% reduction in crashes • 15% reduction in crash rate • $4.3 million benefit from crash reduction ($32,200 per non-fatal crash) • Improved confidence and satisfaction in traffic information • Excellent comprehension of traffic control signs	Phase One study conducted August to December 1995. Study was conducted for the TransGuide system as a whole (i.e., no individual components were examined).
Flow Signals, Houston TranStar, 1996-97 Analysis (7,9) [ramp metering]	• 0% to 24% reduction in travel time • 0% to 33% increase in speed • Annual travel time savings of 431,250 vehicle-hours • $5.555 million benefit from travel time savings ($12.88 per vehicle-hour)	Benefits based upon ramp metering in a single corridor (IH-10), Fall 1996 to Spring 1997.
Ramp Metering, Houston TranStar, 1998 Analysis (8)	• Annual travel time savings of 393,00 vehicle-hours • $5.733 million benefit from travel time savings ($14.97 per vehicle-hour)	Benefits based upon ramp metering in four corridors (IH-45, US 290, IH-10, US 59), all of 1997. Effectiveness of ramp metering was through self-assessment by TranStar personnel.

The benefits of traffic control systems in the U.S. are presented in Table 12. Most of the reported benefits thus far have been attributed to either ramp metering on freeways or traffic-adaptive signal control systems on arterial streets. The results reported in Table 12 can be found in several reports originating from the ITS Joint Program Office in the U.S. DOT. In general, these reports only provide the general magnitude of benefits and contain little information regarding the actual evaluation parameters or scenarios. Thus, it is difficult to critically review these reported benefits when very little information can be gleaned from published reports.

Table 12. Reported Benefits of Traffic Control Systems in the U.S.

ITS Component, Bundle, User Service, or System	Benefits Attributed to Traffic Control Functions	Comments
Ramp Metering, Denver, CO (14,25)	• 5% to 50% reduction in crash rate • 27% to 37% reduction in travel time • 13% reduction in veh-hours of delay	
Ramp Metering, Portland, OR (14)	• 43% reduction in total crashes • 7% reduction in transit travel time	
Ramp Metering, Minneapolis-St. Paul, MN (14,15,26,27)	• 24% to 27% reduction in total crashes • 27% reduction in crash rate • 14% to 27% reduction in travel time	Ramp metering along a single corridor (I-35).
Ramp Metering, Seattle, WA (14,15,16,28,29)	• 38% reduction in crash rate • 48% reduction in travel time • 10% to 100% growth in traffic • 48% increase in average speed	Ramp metering along a single corridor (I-5). Benefits documented in a six-year study of the ramp metering and freeway management system.
Ramp Metering, Detroit, MI (14,16,30)	• 50% reduction in total crashes • 71% reduction in injuries • 7% reduction in travel time • 40% reduction in incident delay* • 42% reduction in fuel consumption*	* Estimates based on no changes in the vehicle miles traveled. Reported benefits are estimated.
Ramp Metering, Long Island, NY (14,31)	• 20% reduction in travel time	
Automated Traffic Signal Control (ATSAC), Los Angeles, CA (15,16,32)	• 41% reduction in vehicle stops • 13% reduction in travel time • 14% increase in average speed • 13% reduction in fuel consumption • 20% reduction in intersection delay	
Automated Traffic Signal Control, Abilene, TX (15,16,33,34)	• 13% reduction in travel time • 22% increase in average speed • 37% reduction in delay • 6% reduction in fuel consumption	

Adaptive Traffic Signal Control, Detroit, MI [SCATS] (16,35)	• 6% reduction in injury accidents
	  • 27% reduction in injuries
	  • 100% reduction in serious injuries
	• 89% reduction in left-turn accidents
	• 19% increase in peak hour speeds
	• 30% reduction in intersection delay
		In addition to SCATS, FAST-TRAC also included improvements in intersection geometry and signal phasing.

Adaptive Traffic Signal Control, Toronto, Ontario [SCOOT] (16,36)	8% reduction in travel time 17% reduction in vehicle delay 22% reduction in vehicle stops 6% reduction in fuel consumption	Benefits from a two-month study of the SCOOT system on two corridors and the CBD, totaling 75 signals.

En-Route Driver Information

Provides driver advisories and in-vehicle signing for convenience and safety.

The National ITS Program Plan (2) describes en-route driver information user service as follows:

> "Driver advisories are similar to pre-trip planning information, but they are provided once travel begins. Driver advisories convey real-time information about traffic conditions, incidents, construction, transit schedules, and weather conditions to drivers of personal, commercial, and public transit vehicles. This information allows a driver to either select the best route, or shift to another mode in mid-trip if desired. Most of the traditional en-route information has been provided via roadside devices (dynamic message signs or highway advisory radio) or via radio broadcasts."
>
> "In-vehicle signing, the second component of en-route driver information, provides the same types of information found on physical road signs today, directly in the vehicle. The service could be extended to include warnings of road conditions and safe speeds for specific types of vehicles, such as autos, buses, and large trucks, but potential users include drivers of all types of vehicles. This service might be especially useful to elderly drivers, in rural areas with large numbers of tourists, or in areas with unusual or hazardous roadway conditions."

The types of deployments already in place or planned over the short term represent a basic level of traffic information dissemination. By using highway advisory radio, changeable message signs, etc., traffic conditions can be quickly communicated to drivers. Similar to many of the ATIS market packages, this service allows travelers to avoid congestion, reducing their travel times by avoiding congestion and incident-related delays. Such benefits are shown in Figure 11.

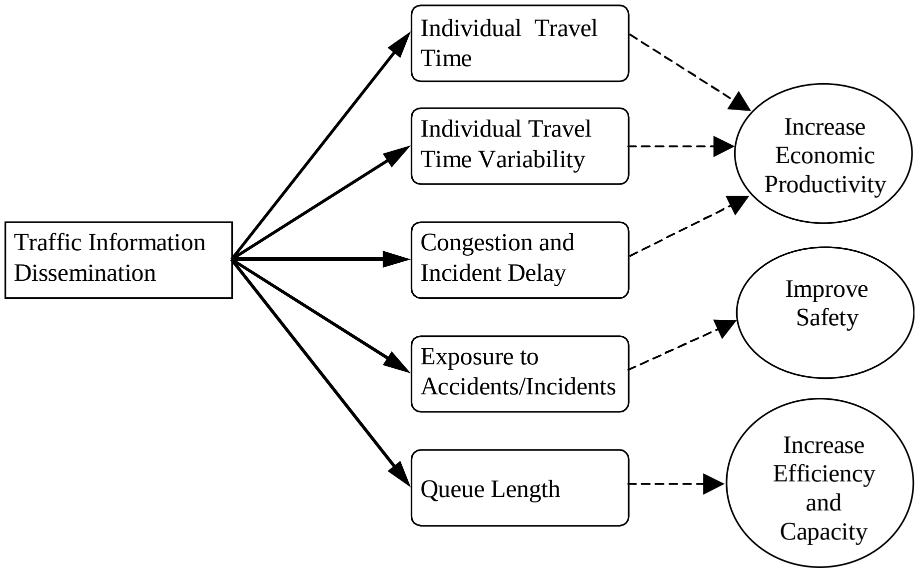

Figure 11. Metrics from Traffic Information Dissemination
Source: Adapted from U.S. DOT, (1), p. 116

Both of these information sources are dependent upon systems in place for the collection of traffic and traveler information and the fusing of that information into meaningful communications. Most of the existing deployments in Texas rely upon more traditional roadside dynamic message signs for communication. Because these systems are expensive to install and operate and have somewhat limited flexibility, most of the more advanced tests of en-route information are using various types of personal or in-vehicle devices. Table 13 lists results from key studies.

Table 13. Reported Benefits of En-Route Traveler Information in Texas and the U.S.

ITS Component, Bundle, User Service, or System	Benefits Attributed to En-Route Traveler Information	Comments
TransGuide, Phase One San Antonio, Texas (10) [en-route driver information component of multi-function traffic management system]	• Drivers surveyed reported significant increase (86% vs. 40%) in confidence in information (compared to traditional radio and TV before). • Percentage "likely" to use alternate routes increased from 58% to 71%.	Based on ongoing survey data for group of 600 downtown commuters.
INFORM (Information for Motorists), Long Island, NY (14,31) [Integrated corridor management system, including ramp metering, variable message signs, and signal coordination]	• Estimated delay savings of 1,900 veh-hours per incident and 300,000 veh-hours annually. • Travelers reported diverting 5 to 10% of the time for passive messages (no action recommended) and 10 to 20% of the time for action messages.	
Ramp Rollover Warning System, Washington, DC (14,37) [speed warning system]	• Eliminated speed-related accidents at the three deployed sites. • Reduced truck speed by 7 mph.	
TravTek, Orlando, FL (14,38) [in-vehicle navigation system]	• No statistically significant impact on accident rates. • Favorable results from driver workload and perception studies. • Predicted crash reduction of up to 4% long term for equipped vehicles.	The evaluation included numerous more detailed assessments of narrow aspects of in-vehicle navigation.
Joint Architecture Team (14,39) [simulation of ATIS benefits for vehicles equipped with in-vehicle traffic information]	• Predicted travel time savings for congested conditions: 8% to 20%. • For traffic conditions not quite congested, predicted travel time savings were 7% to 12%. • Throughput improvements of 10% are predicted for a market penetration of 30% for onboard dynamic route guidance systems.	
Genesis Project Minneapolis, MN (14,40) [System designed to provide incident information via pagers]	• Users reported discovering information about incidents more than half the time via pager, versus 15% of the time via radio or TV. • When alerted via pager, travelers diverted to alternate routes 42% of the time.	Unclear from reports what proportion of travelers received information en-route versus pre-trip.
ADVANCE Project Chicago, IL (14,41) [Dynamic route guidance system]	• Drivers with equipment on board saved an aggregate of 4% in travel time.	Sample size was small with high standard deviation, so only convincing evidence relates to proof of concept.

Critique

Much of what is unknown about en-route driver information has not changed over the years. Drivers want to know about the conditions ahead. It is still not clear whether that knowledge translates into substantive change in travel decisions. Many factors, including site-specific and user-specific characteristics, affect the options available and the traveler's likelihood of choosing one of those options.

With few exceptions, measuring the effectiveness, and therefore the benefits, of en-route driver information will be very difficult. Information services are much more difficult to measure and predict because they require conditional assumptions about driver behavior (42). There may be occasions when the magnitude of response to information is so great that it can be observed, but those situations are uncommon. Most current evaluation plans are using focus groups and surveys to assess customer satisfaction (43). Future evaluations should attempt the measures identified in the National ITS Architecture and shown in Figure 11.

Incident Management

Helps public and private organizations to quickly identify incidents and implement a response to minimize their effects on traffic.

According to the National ITS Program Plan (2), the incident management user service is defined as follows:

> "The Incident Management service uses advanced sensors, data processing, and communications to improve the incident management and response capabilities of transportation and public safety officials, the towing and recovery industry, and others involved in incident response. The service will enhance existing incident detection and verification capabilities to help these groups quickly and accurately identify a variety of incidents and implement a response. The improved response time will minimize the effects of these incidents on the movement of people and goods. This service will also help transportation officials predict traffic or highway conditions so that they can take action in advance to prevent potential incidents or minimize their impacts. While the direct users of this service are the public and private entities responsible for incident detection and response, the ultimate beneficiaries are commercial and transit operators, and the traveling public."

Figure 12 shows the benefit flow diagram identified for incident management systems. Several of the metrics identified are directly measurable, such as the time intervals between the occurrence of the incident and notification of authorities, initiation of response, and arrival on-scene. Likewise, with some degree of error, queue lengths can be measured. Other measures are derived or calculated. As experience grows with incident management systems, the impact that good systems have on these identified measures will become better documented.

The importance of incident management should not be underestimated. When the benefit type analyses conducted by the Joint Architecture Team are extended to the ultimate ITS goals, all of the goals are directly served except for the Mobility goal, which is indirectly served.

Table 14 highlights the primary citations of benefits resulting from the deployment of incident management systems of reasonably recent vintage. The reader is cautioned to recognize that incident management systems and processes vary significantly from location to location. Furthermore, it appears that institutional cooperation and coordination may play a larger role than that played by the deployed technology.

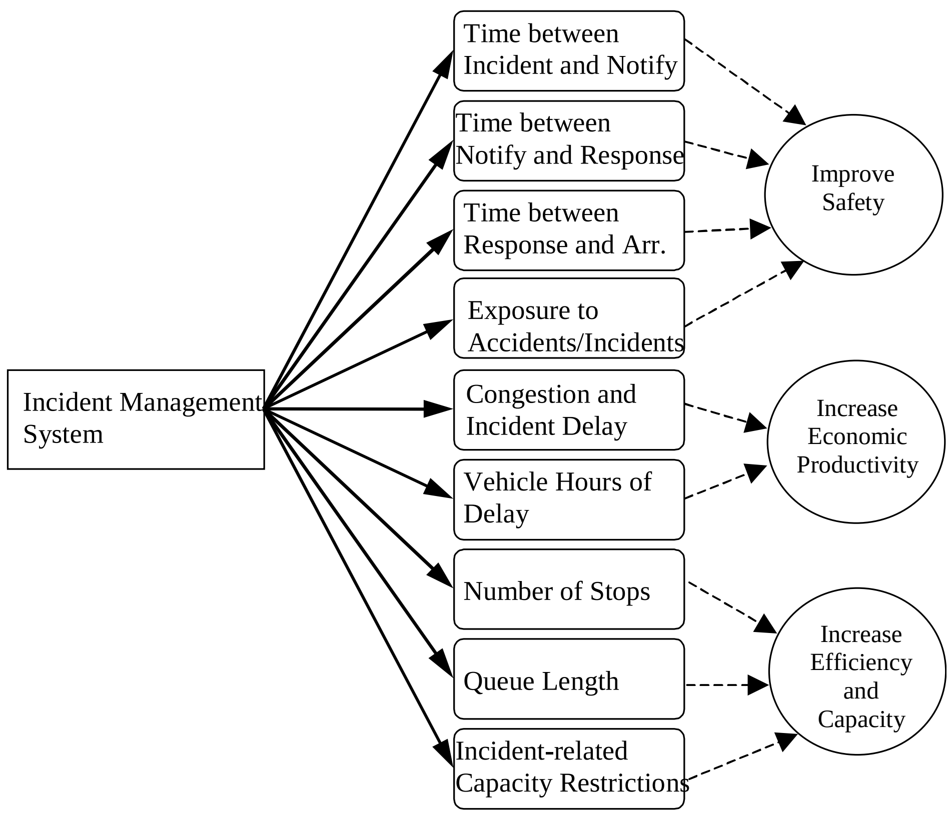

Figure 12. Benefit Flow Diagram for Incident Management
Source: Adapted from U.S. DOT, (1), p. 117

Table 14. Benefits of Incident Management in Texas and the U.S.

ITS Component, Bundle, User Service, or System	Benefits Attributable to Incident Management	Comments
TransGuide Phase One **San Antonio, Texas** (10) [incident management component of multi-function traffic management system]	• 5 minute (21%) reduction in response time to major incidents. • 6 minute (19%) reduction in response time to minor incidents. • Estimated delay savings of 700 veh-hours per major incident, equaling $1.65 M annually in time and fuel.	Based on seven months "before" data and five months "after" data. Analysis does not specify what elements of incident management caused the response time reduction. Delay savings based on simulation.
TranStar **Houston, Texas** (7) [incident management component of multi-function traffic management system]	• Estimated per incident delay savings projected to annual estimate of 570,000 hours and $8.4 M.	Savings estimates based on anecdotal estimates of incident duration reduction of five minutes on major incidents.
TransVision **Ft. Worth, Texas** (13) [incident management system]	• Estimated per incident delay savings of 0.72 hours of lane blockage projected to annual savings of 500,000 veh-hours and $7.3 M.	Savings estimates based on comparison of "typical" historical incidents compared with "managed" incident. Specific time-saving actions not identified.
Gowanus Expressway **Brooklyn, NY** (14,44) [automated incident detection and verification system]	• Time to detect and clear incidents reduced from 90 minutes to 31 minutes (66% reduction), with breakdowns reduced to 19 minutes.	
Atlanta Showcase **Atlanta, GA** (14,45) [Comprehensive traffic management system for 1996 Olympics]	• Incident verification time reduced from 4.2 to 1.1 minutes (74%). • Response time (post verification) reduced from 9.5 to 4.7 minutes (50%). • Clearance time (post verification) reduced from 40.5 minutes to 24.9 minutes (38%). • Maximum time to clear lanes reduced from 6.25 hours to 1.5 hours.	
Early Deployment Study **Detroit, MI** (14,46) [Proposed Freeway Management Center]	• Predicted delay reduction of 40%. • Predicted fuel reduction of 41.3 M gallons (42%). • Reduced emissions: CO - 122,000 tons, HC - 1400 tons, NOx - 1200 tons.	Results based upon computer simulation.

Table 14. Benefits of Incident Management in Texas and the U.S. (Continued)

Los Angeles, CA (47) [Freeway electronic surveillance project on 42-mile network]	• Delay reduced 65%.	Estimation technique not stated.
Maryland CHART Program (14,48)	• Reported benefit-to-cost ratio of more than 5 to 1. • 5% decrease in delay associated with incidents, for annual savings of 2 M vehicle - hours.	No details available to evaluate analysis.
Richardson, TX [Surveillance video link provided to City towing contractor to improve response]	• Undocumented internal city results show that total time to clear an incident has been reduced by 5-7 minutes, on average.	
Los Angeles, CA (47) [Combination of detectors, CCTV and incident management teams]	• Delay reduced 50%. • Estimated benefit-to-cost ratio: 5:1 to 6:1.	Estimation technique not stated.

Critique

Incident management is a user service that has a relatively small ITS component compared to the overall effort of incident management. Admittedly, many of the current deployments have shown anecdotally or conceptually how incident detection or scene management can be augmented by technology. However, there are two distinct shortcomings of most of the incident management evaluations reported herein—age and/or rigor of the analysis. Some of the analyses are more than a decade old, and really evaluate how well the incident management process works, rather than the value of deployed intelligent transportation systems.

Those that are more recent have not demonstrated how the investments made have caused the improvements cited. Although they typically cite a before-after correlation between the presence of a new system and some desired change, they have not shown the cause-effect relationship needed. Further, most of the analyses contain highly dependent multiple layers of assumptions, such as how much the “average” incident duration has changed as a result of the investment. On top of the layers of assumption rest simulations or theoretical estimates of queues and cumulative delay. Finally, there has been a tendency to attach a false sense of precision to calculated results, despite the fact that all of the results are based on assumptions and are at best crude estimates.

Figure 13 is a graphic depiction of the time sequence of events in incident management (49). An effective analysis of incident management will identify which of the elements in the sequence is improved and why.

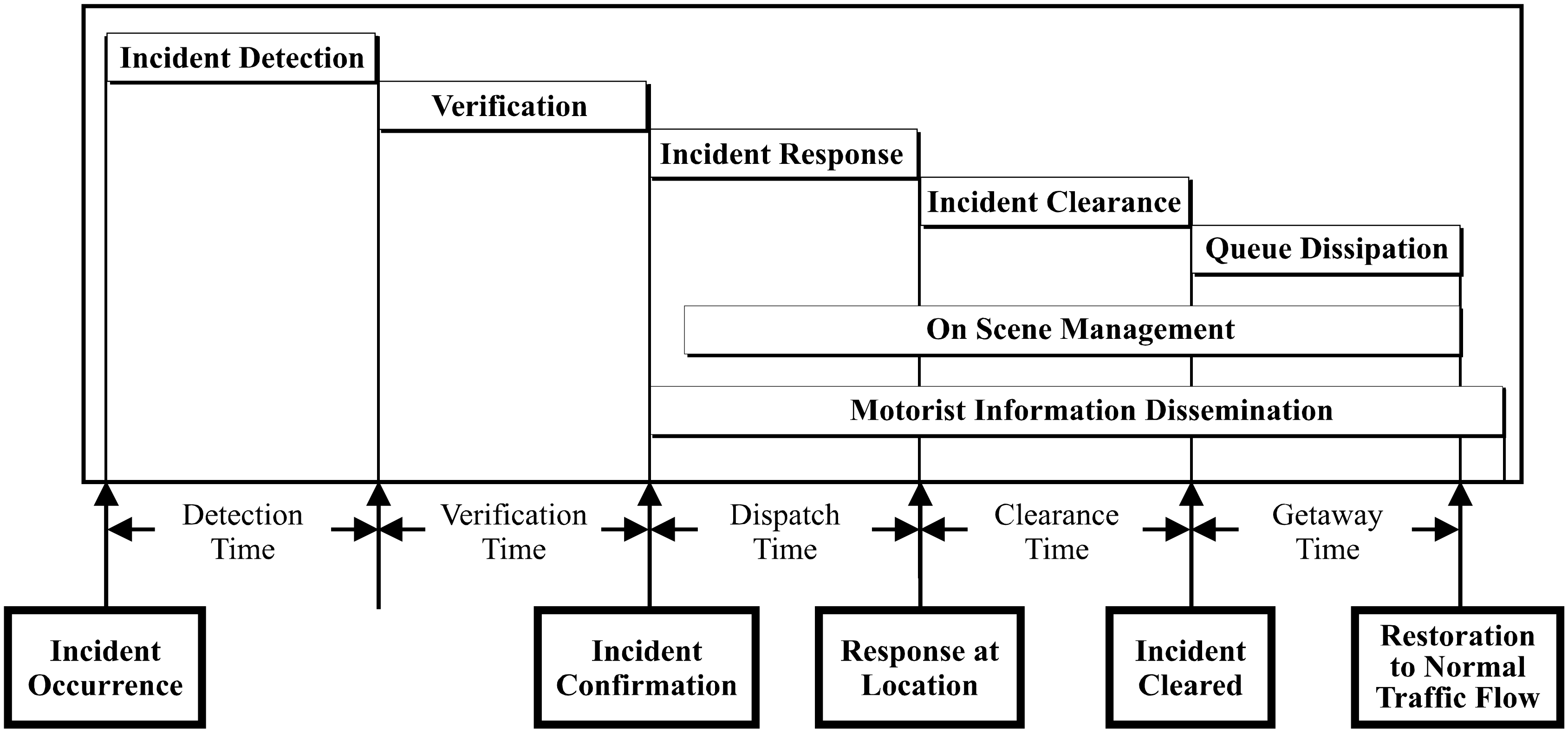

Figure 13. Incident Management Sequence of Events

Source: (49), p. 4

Looking back at the benefit flow diagram for incident management (Figure 12), there is a mixture of metrics that apparently describe the benefits of incident management. Some of those metrics can be measured directly (e.g., time intervals and queue length), while others must be estimated (e.g., vehicle hours of delay and number of stops). Future evaluations of incident management would be most beneficial if they included plans to collect data on specific measures rather than relying on judgment and estimates.

Rail-Highway Grade Crossing Operations

Another priority ITS deployment area for TxDOT is rail-highway grade crossings operations, in which TxDOT is to play a lead role in exploration and deployment. The primary objective of the rail-highway grade crossing user service is to improve safety by providing an advanced warning for train operators and vehicle drivers prior to entering a rail-highway grade crossing. Some projects combine detection technologies with driver information systems. In the near term, the primary opportunities will be in researching effective ways of sharing information between the two traffic streams to improve the safety of each.

Table 15 lists ongoing projects related to the rail-highway grade crossing user service. It should be noted that few benefits have officially been documented for this newer user service. However, Booz-Allen and Hamilton is currently tracking many rail-highway grade crossing ITS projects for the U.S. DOT and will report benefits on these projects in the near future.

Table 15. Benefits of Rail-Highway Grade Crossing Operations in Texas and the U.S.

ITS Component, Bundle, User Service, or System	Expected Benefits	Comments
AWARD, Model Deployment Initiative in San Antonio, TX	• Provides train operators with advance warning of obstacles.	Use of on-board monitors to help operators identify obstacles.
Houston ITS Priority Corridor, TX [train monitoring system]		Application of existing technology to provide driver information systems with real-time status of approaching trains.
Maryland MTA [train warning system]	• Provides drivers with improved notices of approaching trains.	This project is a demonstration and evaluation of a second train warning system with graphic signs and integration with gate control circuits.
Long Island Railroad, NY [integrated intermodal control and warning systems]	• Automatically controls access to intersection (four-way gates).	Project is still in the R&D stage, with possible field test in late 1998.
Los Angeles Blue Line LRT, CA [video-based intrusion/detection enforcement system]	• Automatic enforcement of vehicles running gates. • Up to 92% reduction in violations at one location.	Special legislation was needed to support automatic (video based) citations of drivers.
American Association of Railroads [on-board vehicle proximity alert system]	• Allows for approaching trains (or parts of trains) to signal operators via microwave technology prior to incident.	
Minnesota Guidestar system, [verbal/audio warnings in specially equipped school and private vehicles]	• Provides drivers of specially equipped vehicles audio and visual warnings of obstructed roads and/or approaching trains.	
Gary-Chicago-Milwaukee ITS Priority Corridor [Metro commuter rail line field test of on-board warning systems]	• Six intersections with commuter line are to be monitored in advance, to allow for adequate stop time/distance.	

Texas Experience

To date, there has been limited deployment of rail-highway grade crossing user services in Texas. The Model Deployment Initiative in San Antonio included the AWARD train detection project. The AWARD project consists of six train detection devices positioned at four different intersections. A train presence notification is forwarded to TransGuide operators, who can then post a message near the appropriate exit ramps and frontage roads that are affected by the rail-highway grade crossing. Also in the AWARD project, four trains will be equipped with monitors to enable train operators to visually examine potential hazards at railroad crossings and provide advanced warning of track obstructions. To the authors' knowledge, there has been no studies of the benefits associated with the AWARD project.

The TransLink® ITS Research Center at TTI has defined three distinct "generations" of rail-highway grade crossing interaction:

- **First Generation -** consists of a simple interconnect between the railroad crossing gates and adjacent traffic signals or signal systems. Very simple interaction occurs in this generation, as the adjacent signal or signal system are preempted when the rail crossing gates begin to move into a down position. When the rail crossing gates begin to rise, the adjacent signal or signal system are returned to normal operations. In this generation, very little advance warning is provided on the presence of trains at rail-highway grade crossings.

- **Second Generation -** collects train speed and acceleration/deceleration data at fixed train detector locations and provides more advanced warning of trains at rail-highway grade crossings. In this generation, public highway agencies deploy train detection devices in advance of grade crossings and, using basic speed and acceleration/deceleration data, estimate the train arrival at various downstream grade crossings. This generation does provide a more advanced warning of trains, but can only estimate the expected train arrival time at downstream crossings.

- **Third Generation -** also referred to as positive train separation or positive train control. The third generation consists of private railroad companies instrumenting trains with automatic location devices that can pinpoint the exact location, speed, and acceleration/deceleration at any time. Third generation control potentially will provide more accurate information about train arrival times at grade crossings if the necessary information sharing agreements are formed with the railroads.

The second and third generation of rail-highway grade crossing interaction will provide information about expected train arrival times at rail-highway grade crossings. If these expected arrival times are provided far enough in advance, several ITS strategies can be employed:

- **Improved signal operations -** provide more intelligent preemptive phasing at adjacent signals or signal systems. The primary benefits are reductions in the number of vehicle stops, travel time, delay, fuel consumption, and vehicle emissions.

- **Improved transit operations -** provide train arrival information to transit operators, dispatchers, and vehicle drivers. The primary benefit is increased safety of transit vehicles and passengers near rail-highway grade crossings. In limited cases, transit vehicles could be re-routed around grade crossings to reduce delay and travel time and improved schedule adherence.

- **Improved emergency service operation -** provide train arrival information to emergency service dispatchers and vehicle drivers. The primary benefit is reduced emergency response times as well as reductions in the variability of response times.

The TransLink® ITS Research Center is performing research in second generation train detection along a rail-highway corridor in the Bryan-College Station area. The objectives are to improve traffic signal system, transit service, and emergency service operations by accurately predicting train arrival times at selected rail-highway grade crossings. To date, no actual studies or empirical analyses of benefits have been conducted for this research.

National Experience

In a recent conference paper, Polk reported the following ITS activities related to rail-highway grade crossings (50):

- **Long Island Railroad -** development of a prototype integrated uniform time warning intermodal control system for use at railroad/highway grade crossings. Phase I is still R&D with possible Phase II demonstration at the New Hyde Park station beginning this winter.

- **Los Angeles Metro Blue Line -** this project is implemented to test the use of automatic enforcement of the running of lowered railroad gates. Citations are sent automatically to the owners of vehicles photographed running lowered gates. Due to the success of the program (92% reduction in offenses at one location) the program was expanded to include 17 crossings. No train-vehicle collisions had been reported at the monitored crossings between September 1995 through June of 1997. An important note to make is the need for the California State Legislature to draft a new vehicle provision allowing for the automatic issuance of citations.

- **Vehicle Proximity Alert System -** the American Association of Railroads (AAR) is testing prototype designs (ultimately three) to detect approaching trains and transmit/broadcast the information to specially equipped vehicles. Phase I is at the AAR test track in Pueblo, Colorado. Phase II is to include live track tests in Oregon and North Carolina.

- **Visual and Audio Warnings -** Minnesota Guidestar is testing 30 equipped school vehicles and five equipped railroad crossings located in Twin Cities and Glencoe, Mn. The test is to provide visual and audio warnings to oncoming vehicles after detection of oncoming train(s) using wireless detection and communication technology.

- **Gary-Chicago-Milwaukee ITS Priority Corridor -** this project will equip 300 emergency vehicles, school vehicles, and some passenger vehicles with on-board warning systems for testing at six specially equipped railroad crossings along the Metro commuter rail line.

- **Houston ITS Priority Corridors Railroad Grade Crossing Monitoring System Project -** the purpose of this study is to examine how information systems and traffic control systems can be used to monitor the movements of trains and advise the movements of emergency vehicles to minimize conflict.

Critique

Improved safety and efficiency are the primary benefits identified with ITS deployment at rail-highway grade crossings. The rail-highway grade crossing was a late addition to the National ITS Architecture as the 30th user service. Many of the rail-highway grade crossing ITS deployments in the U.S. are underway, and very few deployments have reported measured benefits. Thus, many of the safety and efficiency benefits identified in this section are either predicted or anecdotal. U.S. DOT is tracking many of these recent ITS deployments at rail-highway grade crossing, so measured ITS benefits information should be available with the next several years.

Pre-Trip Travel Information

Provides information for selecting the best transportation mode, departure time, and route.

According to the National ITS Program Plan (2), pre-trip travel information user services are defined as follows:

> "Pre-trip travel information allows travelers to access a complete range of intermodal transportation information at home, work, and other major sites where trips originate. Real-time information on transit and commuter rail routes, schedules, transfers, fares, and ride matching services are available to encourage the use of alternatives to the single occupancy vehicle. Information needed for long, inter-urban or vacation trips would also be available. Real-time information on accidents, road construction, alternate routes, traffic speeds along given routes, parking conditions, event schedules, and weather information is also included. Based on this information, the traveler can select the best route, modes of travel and departure time, or decide not to make the trip at all."

Table 16 summarizes the primary citations of benefits resulting from the deployment of pre-trip travel information technologies.

Table 16. Benefits of Pre-Trip Travel Information in the U.S.

ITS Component, Bundle, User Service, or System	Benefits Attributable to Pre-Trip Travel Information	Comments
Joint Architecture Project (14,51) [Simulations of ATIS benefits]	• Predicted 21% system-wide delay savings, during incident conditions when alternate route available.	
Detroit, MI (14,39) [Simulation studies of pre-trip route selection]	• Under incident conditions, study showed 90% of benefit associated with en-route information could be achieved pre-trip.	Uncertain what the implications of these findings are.
Smart Traveler Los Angeles, CA (14,52) [Information kiosks in public places components of larger project]	• Positive feedback on the service available, but no information regarding changes in travel or traffic.	
SmarTraveler: Seattle, WA and Boston, MA (14,53) [Commercially provided traveler information service]	• Summary results indicate nearly even split between travelers who reported changing route (45%) and those changing departure time (45%) based on improved information. • Another 5 to 10% reportedly change modes. • Predicted emission reductions: VOC, 25%; NOx, 1.5%; CO, 33%.	Driver behavior based on survey information. Emissions based on simulations that assumed certain levels of participation.
TravTek, Orlando, FL (14,38)	• Predicted emissions: HC, 16% reduction; CO, 7% reduction; NOx, 5% increase.	Assumes 100% market penetration of TravTek - like system.
Atlanta Showcase Advanced Traveler Information Kiosk Project (16,54)	• 92 to 98% of users found information helpful.	Real-time information included accidents, alternate routes, road closures, and congestion.
Marin County, CA Commuter Survey (16,55)	• 69% of respondents stated they would divert, saving estimated 17 minutes each.	Change based on assumption that driver presented information on alternate route and expected time savings.

Critique

Pre-trip travel information represents one of the potentially productive areas of ITS. Timely, accurate pre-trip information has the potential of changing a traveler's mode, route and trip timing at the most effective time and place—before the trip begins. As seen in Figure 11, travel information has the potential of providing benefit to individual travelers. Simulations in the above cited studies indicate that these individual changes have a potentially significant collective impact. However, the collective impact has not been documented to date.

Table 17 is an excerpt from a Volpe National Transportation Systems Center report on the structure of ITS benefits. This table shows that the broadest array of potential direct impacts results from pre-trip travel, where the traveler still has several options available. En-route information is useful, but in a narrower range of opportunity.

Table 17. Direct Impacts of Travel Information on Travel Activity

ITS Strategy	Trip Making	Trip Timing	Mode Choice	Route Choice
Pre-Trip Information and Planning				
• at home	**X**	**X**	**X**	**X**
• at work	**X**	**X**		**X**
• other (like shopping)	**X**	**X**		**X**
En-Route Navigation				
• lost traveler				**?**
• yellow pages				**?**
Dynamic Route Guidance				
• recurring congestion				**X**
• incident				**X**
En-Route Information				
• radio				**?**
Changeable message signs				**X**

Source: adapted from (42), p. 215

Future research should focus on quantifying some of the key measures identified in Figure 11. Improved documentation of these relationships will provide some movement toward the ability to document collective impacts of travel information.

Commercial Vehicle Electronic Clearance

The objective of electronic clearance systems is to facilitate domestic and international border clearance by minimizing the number of required stops.

The CVO Electronic Clearance user service enables transponder-equipped trucks and buses to have their safety status, credentials, and weight checked while traveling at mainline speeds. Vehicles that are safe, legally compliant, and possess no outstanding hours-of-service citations would be allowed to bypass the inspection stations (2). There is the potential for an increase in safety for drivers and station attendants at the roadside inspection facilities due to reduced congestion at weigh stations. Law enforcement would be able to concentrate its efforts on high-risk and non-compliant carriers and operators (56).

Figure 14 shows the benefit flow diagram for electronic clearance systems. Certain metrics within the diagram are readily measured, such as travel time savings for point to point shipping. More general benefits such as manpower savings and operating efficiencies can be derived. Some studies offer estimated savings of fuel, time, and impacts to roadway congestion based upon simulation models.

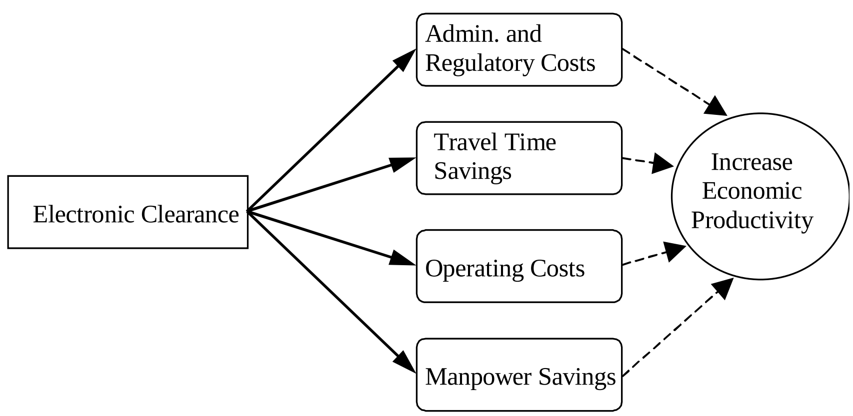

Figure 14. Benefit Flow Diagram for Electronic Clearance
Source: U.S. DOT, (1), p. 123

The following are benefit flow diagrams (Figures 15 and 16) highlighting the likely benefits in the areas of travel time savings and travel related costs, respectively.

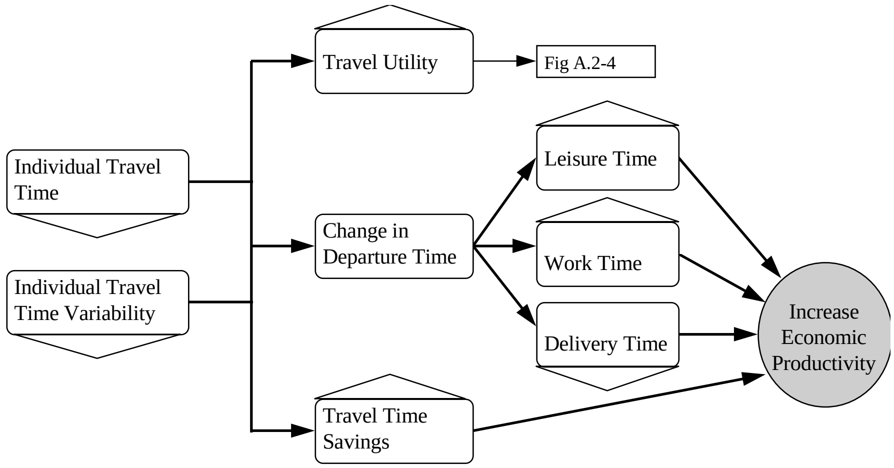

Figure 15. Metrics of Travel Time and Travel Time Variability (Fig. A.2-1)

Source: U.S. DOT, (1), p. 132

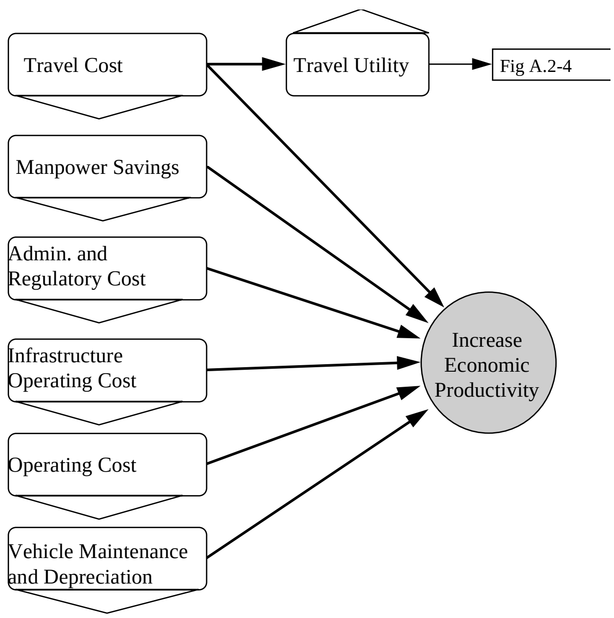

Figure 16. Metrics of Travel Costs and Cost-Related Savings (Fig. A.2-5)

Source: U.S. DOT, (1), p. 133

Table 18 highlights the primary citations of benefits resulting from the deployment of electronic clearance technologies. The reader is cautioned to recognize that many of the reported benefits can be categorized as "estimated" or "projected." It is anticipated that at the conclusion of several projects, particularly those focusing on the creation of databases, will provide a better opportunity for evaluation.

Table 18. Benefits of Commercial Vehicle Electronic Clearance in the U.S.

ITS Component, Bundle, User Service, or System	Benefits Attributable to Commercial Vehicle Electronic Clearance	Comments
Advantage I-75 Project (57,58) [Mainline Automatic Clearance System (MACS) at 30 stations. Participating states: Florida, Georgia, Tennessee, Kentucky, Ohio, Michigan, Ontario, Canada]	• Early B/C ratio estimates were 7:1 for carriers. • Average of 2 to 3 eliminated stops per equipped vehicle. • 0.05-0.18 gallons saved per avoided stop.	Over 4,500 vehicles participated in the first phase of the study.
International Border Crossing Detroit, MI - Windsor, Ontario (59) [automatic vehicle identification and statistic information]	• Estimated B/C ratio of 4:1.	
National Governor's Association Study (60)	• B/C ratios of 1:1 - 7:1 for eight states using electronic clearance technologies.	
Mitretek Simulation Study (39)	• 20% transponder equipped vehicles generated a 30 seconds time savings per vehicle. • 60% equipped vehicles generated an 8 minute time savings per vehicle.	Simulation study used to estimate benefits. Examined the impacts to delay when commercial vehicles were equipped with transponders allowing for the transmission/ reception of information electronically. Compliant trucks equipped with transponders were permitted to bypass the stations.
Univ. of Pennsylvania Study (61)	• Expected B/C ratio of 4:1 for small carriers. • B/C ratio of 20:1 for carriers with 100+ vehicles.	
AMASCOT (Automated Mileage and State Line Crossing Operational Test) (62)	• 33 to 55% reduction in fuel tax and registration costs.	Uses GPS technology.
State of Colorado Study, Using AVI and WIM technologies (56)	• B/C ratios of 7:1 to 10:1 for motor carriers using electronic clearance technologies.	

Critique

Currently, too many of the expected benefits, such as time travel savings, or substantial reductions in fuel taxes are the results of simulation studies and not documented data. In addition, integration among the various systems remains a problem. Certain studies use technology along a given corridor, but do not mesh well with similar studies elsewhere (57, 61). Electronic Data Interchange difficulties between and among various state agencies can create gaps in the information provided by an interstate motor carrier. Standardization of the systems, as well as greater participation among the motor carriers could considerably improve the quality and reliability of the documented benefits.

Commercial Vehicle Administrative Processes

The objective of advanced or ITS technology based administrative processes is to provide for electronic purchasing and auditing of credentials as well as the automated reporting of fuel consumption and mileage rates.

Within this definition are vehicle registration, carrier-operating authority, fuel tax registration, and permitting for the movement of over dimensional vehicle and hazardous materials (63). Electronic purchasing of credentials would provide the carrier with the means to obtain annual/renewable credentials via computer. It would reduce extension paper and time demands for state agencies and motor carriers (61). Other benefits include the development of a digital database, which could streamline future applications from a pre-registered motor carrier. Several studies have shown that, at least initially, there is a strong argument for electronic data systems in terms of reduced processing time and repetitive paperwork. The benefit flow diagrams (Figures 16 and 17) outline the expected benefits from the implementation of ITS technologies in the area of CVO Administrative Processes.

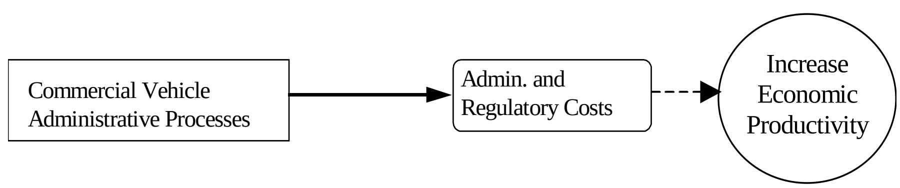

Figure 17. Benefit Flow Diagram for Commercial Vehicle Administrative Processes
Source: U.S. DOT, (1), p. 123

Table 19 outlines the primary citations of benefits resulting from the use of ITS technology within the area of CVO Administrative Processes. Please note that while some of the studies offer strong documented evidence of increased efficiencies, some of the statistical data is derived from personal testimonies and not necessarily direct accounting methods.

Table 19. Benefits of Commercial Vehicle Administrative Processes in the U.S.

ITS Component, Bundle, User Service, or System	Benefits Attributable to CVO Administrative Processes	Comments
HELP, Electronic One-Stop Shopping [Heavy Vehicle Electronic License Plate program using AVL, WIM, AVC, and EDI technology]	• Decrease in HazMat incidents (valued at up to $1.7M/year). • 5% decrease in overweight loads (up to $5.6 M/year). • Estimated B/C ratios of up to 12:1 for governments. • $160,000 decrease in annual operating costs for weigh stations. • $500,000 to $1.8M annual savings from decreased tax evasion.	Estimated benefits are projections based upon previous experiences and upon comparison with other databases. Tested along I-5, I-10, and I-20 trucking corridors to facilitate electronic data collection, credentialing, and permit approval processes.
ATA Foundation, Evaluation Study (64)	• 20% increase in loaded mileage. • 6% reduction in “deadhead” miles. • 50 to 100 additional miles/driver/day. • Reduced need for driver contact with dispatcher (valued at 15 min/day/driver ~ $10k/year). • Lower insurance premiums (expected) due to vehicle tracking and location services.	See discussion following this table.
Oregon DOT Information Network (65)	• 400% increase in safety inspections with a 23% increase in staff.	ODOT “Green Light” Program: set up to electronically verify safety inspection and weight information of vehicles, drivers and carriers from fixed and mobile roadsides sites at highway speeds. Also provides vehicle operators with road condition, weather, and downhill speed information.
Upper Great Plains Transportation Institute Inspection Selection Systems (66)	• 50% increase in detection of unsafe vehicles/drivers over conventional methods.	
Massachusetts Metropolitan Transportation Authority study (67)	• Projected annual savings of $2.4 million in administrative compliance costs.	Estimated benefits.

Table 19. Benefits of Commercial Vehicle Administrative Processes in the U.S. (Continued)

AMASCOT-Automated Mileage and State Line Crossing Operational Test (63) [Uses GPS technology to record and report mileage for fuel tax purposes.]	• 33 to 55% reduction in fuel tax and registration costs. • Interviewed staff from auditing personnel cited improved accuracy of records.	Much of the information provided is anecdotal and estimated benefits based upon the experience of interviewed personnel. Motor carriers and state agencies from Iowa, Wisconsin, and Minnesota participated in this test.
Advanced Vehicle Monitoring and Communication (AVMC) (17,61)	• 9 to 16% increase in loaded mileage. • $0.12 to $0.20 decrease in operating costs per mile.	Used by Telsat Shipping of Canada.
Two-way Data Systems, J.B. Hunt Trucking (17)	• 20% reduction in driver turnover. • Allows for drivers to contact family members. • Increase of 20-25 miles/driver/day. • Increase in driver productivity.	Use of on-board computers and AVL technology to improve communications to/between operators used by J.B. Hunt Trucking.
Midwest States One-Stop Electronic Purchase (MEOSS) (63) [Potential to allow a motor vehicle carrier to apply, purchase, and receive all necessary permits for a multi-state trip from one location]	• Considerable time savings in processing of applications. • Creation of electronic database for regulating agencies.	Less than 50 credential transactions were undertaken during all three One-Stop programs. Participating states: Minnesota, Iowa, Illinois, Kansas, Missouri, Nebraska, South Dakota, and Wisconsin.
Southwest Electronic One-Stop Shopping system (EOSS) [Similar to the MEOSS system: using a PC based system, motor carriers could submit requests for IRP, IFTA, and SSRS credentials, and compliant, pre-approved carriers could receive approved credentials via computer]	• Creation of electronic database. • Carriers are able to file IRP, IFTA, and SSRS credential applications.	Limited participation despite favorable welcome from agency personnel. Participating states: Arkansas, Colorado, and Texas.

ATA Foundation

In a study commissioned in 1992 by the American Trucking Association Foundation it was determined that the use of portable diagnostic equipment could reduce the time to conduct a safety inspection by up to 10 minutes. The study also recorded the following cost savings for the participating motor carriers (64):

- In Minneapolis, Minnesota: applied ITS technologies provide reduced need for communication with dispatchers. The daily savings (estimated at 15 minutes per driver per day) is cost factored as an estimated $10,000 saved per month for the Best Line Trucking Company.

- United Van Lines expects a reduction in theft insurance premiums due to the use of advanced vehicle location and tracking systems.

- Schneider of Green Bay Wisconsin experienced a 20 percent increase in loaded mileage. ITS technologies have allowed for the elimination of driver check-in phone calls (saving an estimated two hours per day) which allowed for increased driver salaries.

- Trans-Western Ltd. Off Lerner, Colorado uses an advanced fleet management system to better driver relations (resulting in a lower driver turnover rate and increased daily mileage).

- North American Van Lines has increased the number of shipments by 17 percent, reduced the number of “deadhead” miles by six percent and reduced the number of cancellations by use of advanced vehicle monitoring and communication systems.

The Midwest Electronic One-Stop Shopping system (MEOSS) was developed to demonstrate the applicability of ITS technologies in improving the operating efficiencies of commercial vehicle permit application and credential approval processes. There was software designed to automate portions of the application processes and thereby reduce the overall time needed for motor carriers to obtain operating permits. Carriers could, via a personal computer, complete applications electronically and then submit them to the state agency for review using a modem. Thirteen motor carriers, two leasing companies, one motor carrier association, and agency representatives from the states of Minnesota, Wisconsin, Illinois, Missouri, Kansas, Nebraska and South Dakota took part in the test. MEOSS was set up so that a participating motor carrier could apply for IRP, IFTA, SSRS, and OS/OW permits.

Critique

One major drawback to the reported findings is the lack of substantial participation from motor carriers. Any significant savings are undermined in value due to the scarcity of comparable experiences. In addition, much import was given to impressions of benefits: from ease of use to employee morale. While these are indeed benefits, they are hard to predict in a reliable manner and are extremely subjective. Development of an extensive and flexible electronic database would certainly aid the regulatory agencies, however, some information is still entered manually by an operator after being submitted in the conventional manner by the motor carrier.

The private carriers are more interested in fleet vehicle monitoring and driver/vehicle scheduling efficiencies, than providing detailed electronic inventories to an oversight agency. This issue reveals the conflict in methods between the private and public sectors, each of whom seek improved operating efficiencies: one using micro-level information and accounting practices, the other seeking standardization across an industry.

CHAPTER 4—FINDINGS

The authors offer the following findings and conclusions based upon the first year of study of ITS benefits.

EXISTING ARCHITECTURE FRAMEWORK

National ITS Architecture documents define ITS goals and evaluation criteria that closely parallels TxDOT's transportation goals in the most recent 20-year "Texas Transportation Plan." The National ITS Architecture benefits evaluation framework could serve as the basis for TxDOT's ITS evaluation methodology, with some adaptation for statewide conditions, goals, objectives, constraints, etc. The JPO's use of a "few good measures" clearly provides a common set of performance metrics by which to compare and track ITS deployment in the U.S.

UTILITY OF EXISTING JPO REPORTS

The ITS JPO has published (in reports prepared by Mitretek, Apogee Research, and Hagler Bailley) the most comprehensive account of ITS benefits that the authors could identify. The JPO reports, however, do not provide a critical review of reported ITS benefits nor the detailed information necessary for others to critique the reported benefits. In many cases in the JPO reports, similar ITS user services generated a wide range in the reported benefits. The large variability in the reported benefits were most likely due to varying pre-existing conditions with each ITS deployment. However, the JPO reports provide little to no information on these conditions or the relationship between these varying conditions and the reported ITS benefits.

TXDOT DEPLOYMENT FOCUS AREAS

There are numerous benefits studies in each of TxDOT's major deployment areas, with the exception of rail-highway grade crossing (due in part to the later inclusion of this user service in the National ITS Architecture). The reported benefits for commercial vehicle electronic clearance and administrative processes are mostly anecdotal or predicted, as indicated by the benefits tables in Chapter 3. More information on each of TxDOT's major deployment areas is provided below:

- **Traffic Control -** The literature review clearly establishes that significant benefits accrue from the implementation of one or more of the principal packages that are part of "traffic control." It is likely that most deployments will produce statistically significant improvements in key measures, such as crashes, travel time, and delay. The analytical approaches to date have not been consistent, so it is not possible to draw conclusions based on the totality of experience. Furthermore, because the analyses have relied on numerous assumptions, it is not prudent at this time to draw quantitative conclusions as to the magnitude of probable benefits.

There are two near-term remedies to mitigate this shortage of meaningful performance information. The first is a recognition on the part of implementing agencies that many long-standing practices in traffic analyses do not necessarily produce meaningful results in ITS analysis. Those agencies would be well served to examine the benefits flow diagrams and focus their evaluation efforts on rigorous pursuit of the metrics and associated data indicated therein. Most of the pertinent benefit flow diagrams are shown in Chapter 3 of this report.

The second and subsequent years of this research project should produce more rigorous critiques of previous analyses. To the degree that original analyses can be obtained, they will be analyzed in terms of the national architecture. The resulting benefits should provide at least some remedy to the shortage of quality information.

- **En-Route Driver Information -** With a few exceptions, most of the evaluations of en-route driver information have concentrated on in-vehicle devices, which are viewed by many as the future of this service. However, at this time the primary means of providing information to travelers en masse is via roadside devices such as dynamic message signs. The literature contains some evidence of general effectiveness, and quite a bit of support from surveys of users who desire good information. But no study yet has clearly established the causal relationship between en-route information and the types of measures commonly used to establish the performance of surface transportation systems. Future research should focus on metrics consistent with the planning in the national architecture.

- **Incident Management -** This service will ultimately prove to be simultaneously one of the most valuable and one of the most difficult to measure. Results to date are consistent with intuition and suggest very large benefits. Annual savings in non-recurrent delay of more than 500,000 vehicle-hours in portions of a network, or percentage reductions in non-recurrent delay of 40% to 60% are very significant and not uncommon. There appears to be ample support of aggressive deployment of incident management.

  In spite of these very large estimates, the quantification of benefits from incident management systems remains hindered by two factors. First, of all the ITS "User Services," incident management is possibly the most vulnerable to non-ITS shortcomings. The ITS components can perform perfectly, but without concomitant human and institutional performance, the end product is not worth the ITS investment. Thus ITS investment in incident management needs to <u>follow</u> the commitment from institutions and individuals.

Second, estimates of performance of existing incident management systems are plagued by the same kinds of assumptions as the traffic control estimates. Future evaluations of incident management must be clearly focused on the applicable metrics and on securing sufficient quantities of the right data to avoid the necessity of overlapping assumptions.

- **Rail-Highway Grade Crossing Operations -** There are substantial intuitive benefits associated with this service, which addresses many long-standing needs in the areas of safety and reduced motor vehicle delay associated with grade crossings. All projects are in either the research and development or evaluation phases. There are no quantitative benefits available.

- **Pre-Trip Travel Information -** This service has great potential for impacting travel demand. Like en-route driver information, this is a service that will be difficult to measure. Results to date reflect public reaction to information available, along with the stated intent of the public to modify their travel as a result of the information that is or might be available. However, the direct benefits associated with the relationship between pre-trip information and system performance measures have been established. Likewise, the only measurements to date are customer satisfaction. Future evaluations should attempt to measure other metrics associated with traffic information dissemination, such as those shown in Figure 11.

- **Commercial Vehicle Electronic Clearance -** The greatest potential benefits from electronic clearance programs lay with the motor carriers. Savings in travel time, and/or fuel consumption in particular are recurring areas of interest, but not always persuasive given how many trucking companies operate. With the development of international clearance standards the international borders might see significant improvements in throughput volumes, enabling enforcement personnel to focus on non-compliant vehicles. The low participation rates in some studies are indicative of the “wait and see” attitude that private enterprises employ when innovative procedures are introduced. It is expected that as benefits occur and as transporters realign their service policies, motor carrier participation will increase. Initial perceptions on the part of regulatory agencies have been positive, particularly when discussing perceived or predicted reductions in operating costs.

- **Commercial Vehicle Administrative Processes -** Unfortunately, many initial program phases engendered little participation from established motor carriers. Integral to the success of most programs is the creation of electronic databases, accessible by both motor carriers and regulatory agencies. With greater participation, and more standardization of the information provided among the participating states, large time savings are expected for the administrative process.

Motor carriers are developing company specific programs that offer a more specific set of advantages, for example, automated vehicle location technologies, or en-route communication networks between dispatchers and operators. Some attention should be given to the development of standards for electronic data interchange between private motor carriers and the regulatory agencies responsible. Digital versions of existing forms may prove the most readily accepted means of creating electronic databases, even though the information provided may not be the most thorough.

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