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16. Abstract

This report summarizes the results of a multi-year research project that looked into the benefits of deploying intelligent transportation systems (ITS) projects. In this report the researchers:

- summarize current estimates of the benefits of ITS deployments, and
- present detailed guidelines for evaluating existing ITS projects and for estimating potential benefits of prospective projects.

In addition to describing what ITS is, the report addresses the range of benefits that can be expected from ITS deployments, identifies key sources for updated benefits information in a highly dynamic field, and develops a sound and consistent approach to setting goals and objectives and to measuring the benefits of ITS deployments. Using the detailed evaluation guidelines, the report identifies data collection and evaluation methodologies for 28 of the most commonly deployed market packages. Detailed evaluation "trees" are presented in an appendix. These trees lead the user through a comprehensive assessment of the goals, objectives, measures of effectiveness, and data requirements for each of the 28 market packages. Additional appendices present detailed recommendations for analytical approaches to specific analyses associated with various measures of effectiveness.

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ITS BENEFITS:
GUIDELINES FOR EVALUATING ITS PROJECTS

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was William R. Stockton, Texas P.E. #41188.

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This project was conducted in cooperation with TxDOT and FHWA. The authors thank the members of TxDOT's Project Monitoring Committee: Pat Irwin (SAT), Sally Wegmann (HOU), Brian Burk (AUS), Janie Light (TRF), and Mel Partee (TRF). Special thanks go to the project director, Darren McDaniel (TRF), and the program coordinator, Al Kosik (TRF). Their guidance and patience were invaluable to the research team. Finally, thanks to district staff members that the team visited for their feedback and assistance in developing meaningful measures and approaches.

While this report presents an important step forward in achieving consistency in the documenting of ITS benefits, the authors acknowledge that much work remains to be done and commend future contributors to continually improve the processes and results contained herein.

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CHAPTER 1: INTRODUCTION

This report is the culmination of a multi-year project to assist the Texas Department of Transportation (TxDOT) in identifying the benefits of intelligent transportation systems (ITS) projects.

PURPOSE

There are two primary purposes of this report:

1. to provide current estimates of the range of benefits that can be achieved through the deployment of ITS projects, and
2. to provide detailed guidelines for estimating benefits and evaluating ITS opportunities and projects.

To meet those purposes, the report attempts to answer these questions:

- What is ITS?
- What are the ranges of benefits that can be expected from the deployment of ITS projects?
- What are the most valuable sources for up-to-date information on the highly dynamic and ever-changing subject of ITS benefits?
- What is the most sound and consistent approach for setting goals, objectives, and measures for ITS deployments?
- What data should be collected to support sound investment objectives and continued efficient operations of ITS projects?

In this report the researchers attempt to provide TxDOT with the framework, the tools, and the range of benefits needed to make effective decisions on existing and future ITS deployments. It does not attempt prescriptive direction on specific deployments, particularly future deployments, as they are highly context-driven.

SCOPE

This report focuses on the ITS projects, market packages, and user services that are the most common current and near-term deployments, specifically, the types of deployments that TxDOT and local agencies in Texas are likely to deploy in the next five to seven years. Generally, these deployments are the public agency and "intelligent infrastructure" projects. Intelligent vehicle packages are not addressed in similar detail because those packages are generally deployed by the automotive and other private-sector industries, with the primary public agency interest being effective interface. Compliance with the national architecture virtually assures effective interface.

ORGANIZATION OF THE REPORT

Included in this introductory chapter is a discussion of the background, in particular the national context, of ITS deployment. That discussion introduces the national goals and objectives and national architecture, and provides the reader with a description of the commonly used terms, such as "user services" and "market packages."

Chapter 2 contains a summary of the benefits that have been documented to date. Ranges of potential benefits from a variety of ITS applications are presented in summary form. The Federal Highway Administration (FHWA) has an ongoing project to accumulate and distill the benefits of ITS projects nationwide and worldwide, rapidly populating the database of quantifiable information about the impacts of ITS projects. Because this information changes so rapidly, and because the science of benefits prediction has not sufficiently evolved, this report does not attempt to present predictive techniques or definitive estimates of benefits. Readers will be better served by using the updated websites identified in that chapter.

Chapter 3 presents the general framework for performing evaluations and estimating benefits. That chapter is critical because it represents a major step in remedying the shortcoming of most ITS evaluations – inconsistency of approach and measurement.

Chapters 4 and 5 provide extensive detail on the application of the evaluation framework to evaluation plans and to the evaluation of specific market packages. Chapter 5 is the link to the detailed appendices. It also provides the reader with answers to the question: "What data should I collect?" on a market package-specific basis.

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:

- ITS components,
- the surface transportation system, and
- 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 that attempts to show how ITS functions and stakeholders are interrelated (*1*).

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, ITS 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 achievable. These objectives are very important in that they are a forerunner of the benefits measurements that will be discussed in detail later.

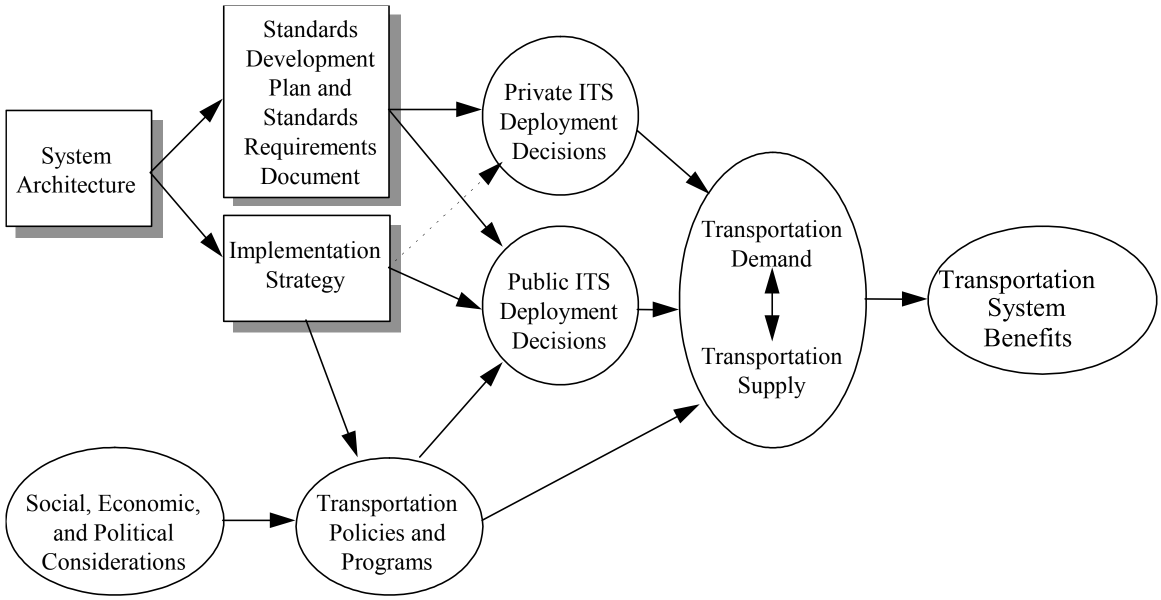


Figure 1. The Relationship of ITS System Architecture to Benefits.
(Source: United States Department of Transportation (USDOT), (*1*), p. 37)

ITS Goals

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

- 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; and
- enhance the present and future economic productivity of individuals, organizations, and the economy as a whole.

ITS Deployment 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 Benefits 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 ▪ Decrease personal costs of travel ▪ Increase awareness, and ease of use of transit and ridesharing 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
Create an environment in which the development and deployment of ITS can flourish

Source: USDOT (*2*)

NATIONAL ITS ARCHITECTURE

The national ITS architecture exists to assist agencies in determining, at each step of project development, how the project fits into the larger regional context of transportation management. The architecture consists of three basic components: user services, logical architecture, and physical architecture.

User Services

A user service is the benefit of the ITS from the perspective of the user. The user could be the general public or it could be a system operator. Various user services have been bundled together into eight general categories. Table 2 is a listing of the current user services and the respective bundles.

Practitioners typically will be interested in the equipment packages and market packages that represent the devices and functions identified for deployment.

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

Table 2. ITS User Services (Continued).

	▪ 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
Information Management	▪ Archived Data Function
Maintenance and Construction Management	▪ Maintenance and Construction Operations

Source: USDOT, (*2*)

Logical Architecture

Each user service has specific requirements that allow the specific service to be accomplished. The requirements, found in the *logical architecture*, serve as starting points in building an architecture. The *logical architecture* is a tool to assist in organizing entities and relationships (see Figure 2), as well as the various processes and information flows of a system. The logical architecture exists solely to define the functions and flows, not to make a determination of who does what for implementation.

The national ITS logical architecture defines a set of functions and data flows that responds to each user service requirement. Each of the functional processes can be further broken down into subsystems or sub-functions. After the process is broken down to the lowest level of detail, process specifications (PSpecs) emerge. These PSpecs are the basic functions that must be performed to meet the user service requirements.

Physical Architecture

The *physical architecture* takes the PSpecs and assigns them to physical entities (see Figure 3). The data flow from the logical architecture that flows from subsystem to subsystem and are grouped together into physical architecture flows. The national ITS architecture describes the physical architecture by dividing it into two layers: a transportation layer and a communications layer. The transportation layer (larger boxes in Figure 3) shows the relationships between the management center and the objects with which it interacts. This layer may include field devices, travelers, vehicles, and the transportation or emergency management centers.

The communications layer (smaller ovals in Figure 3) depicts the communications that are necessary to transfer information among the components of the transportation layer. This layer clearly identifies the system interface points where national standards and communications protocols can be used.

The logical and physical architectures contain the elements needed to provide the user services.

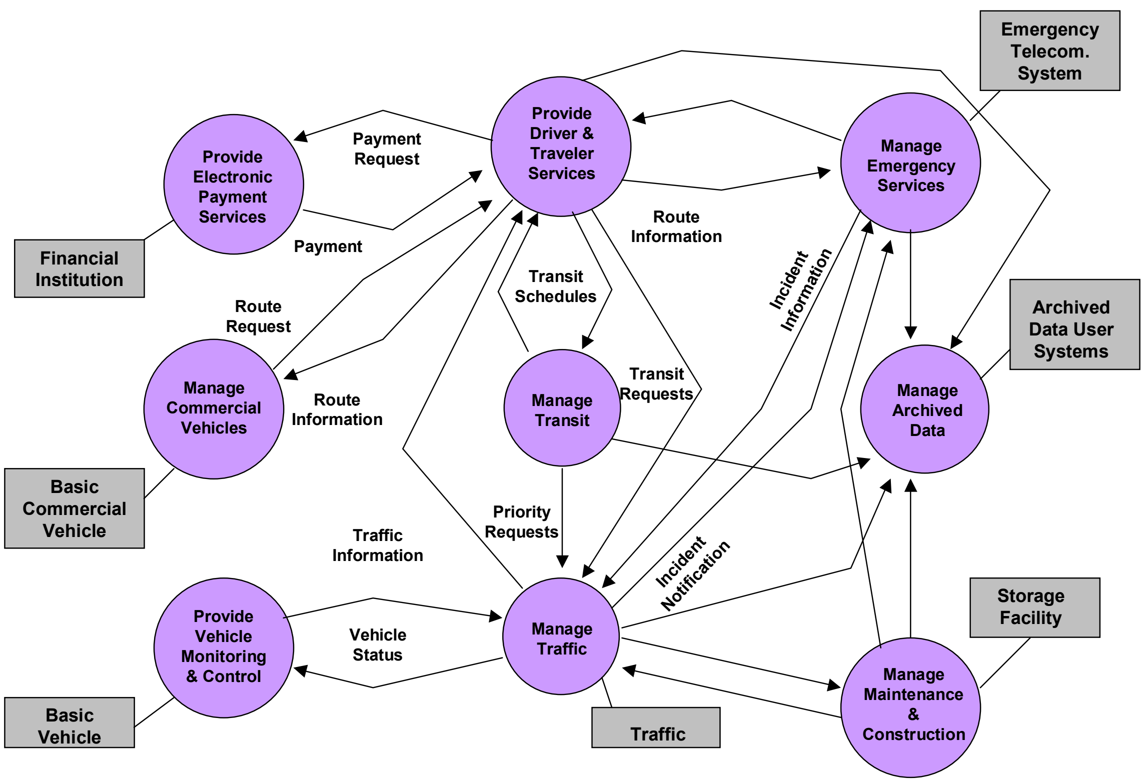


Figure 2. Complexity Figure.

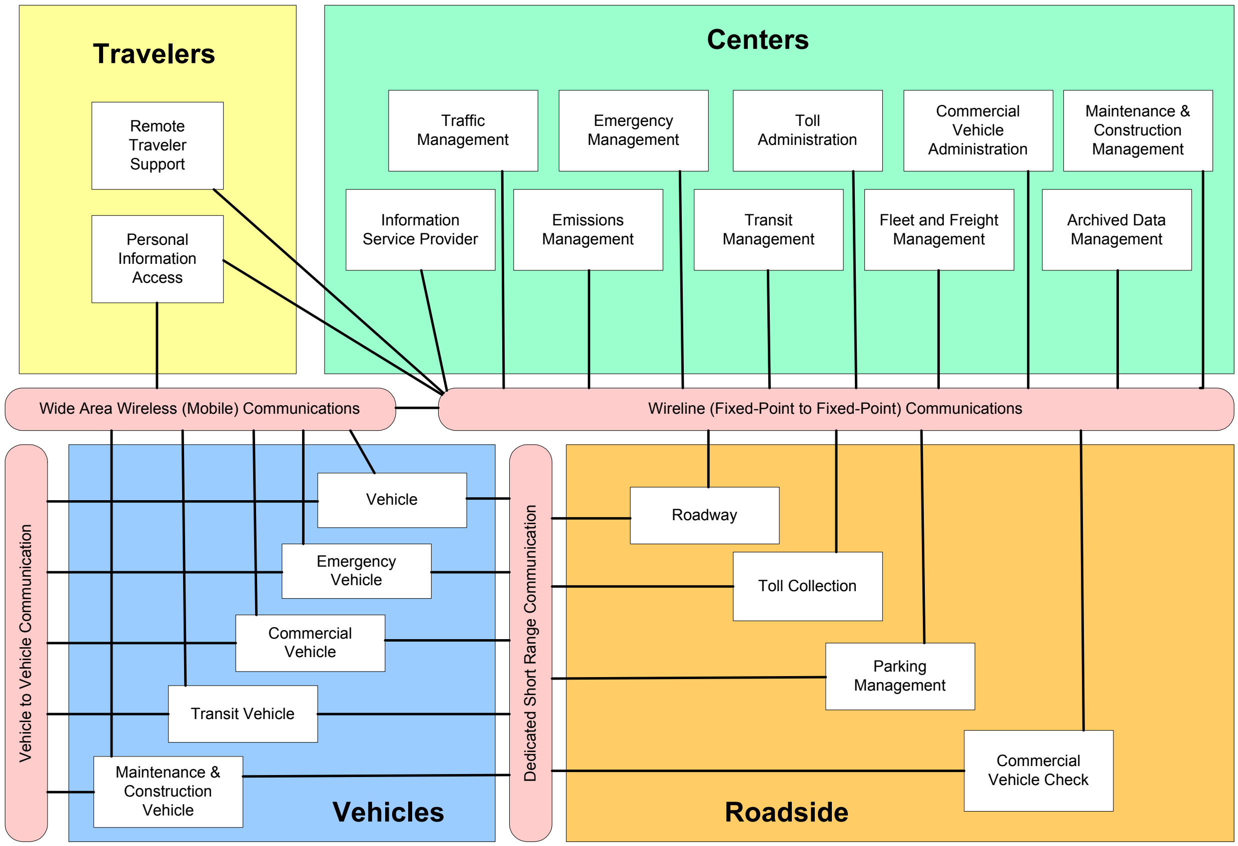


Figure 3. Physical Architecture.

Equipment Packages

The functions or PSpecs of a subsystem may also be grouped into implementable packages of hardware and software, known as equipment packages. There are more than 175 identifiable equipment packages. They may be associated with market packages and are used in estimating deployment costs.

Market Packages

Market packages are further definitions of the user services, grouped in practical deployment modules, rather than by user service. These market packages are designed to more accurately distinguish between major levels of functionality and take into account various institutional environments. They are more deployment-oriented ITS service building blocks. Most market packages are made up of equipment packages of two or more subsystems.

Table 3 shows the relationship between the user services and 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

Table 4 shows early work by the Joint Architecture Team that focused on qualitatively identifying the benefits of the various market packages. 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. 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
		ITS System Goals				
Advanced Public Transit Systems (APTS)	Transit Vehicle Tracking		**	*		
	Fixed-Route Operations		**	*		*
	Demand-Responsive Operations		**	*		*
	Passenger and Fare Management					**
	Transit Security				**	
	Transit Maintenance					*
	Multi-Modal Coordination		*			*
Advanced Traveler Information Systems (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		*		*	
Advanced Traffic Management Systems (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 3. Benefits of Market Packages for Achieving ITS System Goals (con't).

	Market Packages	Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity
Commercial Vehicle Operations (CVO)	Fleet Administration		***			
	Freight Administration		***			***
	Electronic Clearance	**	***			***
	CV Administrative Processes					**
	International Border Electronic Clearance	**	***			***
	Weigh-in-Motion	**	***			***
	CVO Fleet Maintenance	**			**	**
	HAZMAT Management	**			**	**
	Roadside CVO Safety		**		**	**
	On-board CVO Safety				***	**
Advanced Vehicle Safety Systems (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	***	***		***	
Emergency Management (EM)	Emergency Response			*	***	**
	Emergency Routing			*	***	**
	Mayday Support				***	*
ITS	ITS Planning	**	**	**	**	**

Key: * = low benefit; ** = moderate benefit; *** = high benefit.
Source: USDOT, (*1*)

REVIEW OF TXDOT ITS DEVELOPMENT 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 ITS simultaneously, the *Strategy* identifies key areas where TxDOT would take a lead role or a critical support role.

Table 4 is the summary table from the *ITS 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 4. 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: — = Typical Lead Role; ˜ = Alternate Lead Role; = Typical Support Role
Source: TxDOT, (3)

CHAPTER 2: ITS EVALUATION FRAMEWORK

This chapter discusses reasons for evaluating ITS and summarizes the components of several existing ITS evaluation frameworks, including the framework suggested by the U.S. Department of Transportation in the national ITS architecture. The latter part of this chapter presents a proposed generic ITS evaluation framework that TxDOT can use to quantify project-specific ITS benefits and impacts in Texas.

WHY EVALUATE ITS?

Before providing significant detail on specific ITS evaluation methods, this report reviews why we evaluate ITS. The reasons for evaluating ITS provide a context for developing an ITS evaluation framework and corresponding measures. Transportation professionals should perform ITS evaluations to accomplish the following goals:

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

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

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

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

Figure 4 shows the hypothesized evolution of ITS evaluations. To date, many ITS evaluations have been focused primarily on the first function (i.e., quantifying the impacts of ITS). A focus on the absolute monetary benefits of ITS has been necessary to convince policy-makers and other non-technical decision-makers that ITS technologies and applications are mature and ready to be deployed. Although these benefit studies have been necessary to convince policy and decision-makers that ITS can be a worthwhile investment, the research team suggests that the information from these benefit studies has contributed marginally to a much-needed broad database that would help in making future investment decisions, and even less in optimizing transportation system operation. Based upon Figure 4, the authors suggest that to better meet the emerging needs in transportation, ITS evaluations will need to concentrate on the "why?" and "how?" of ITS impacts (and not just the absolute monetary magnitude) to help guide future investment decisions and optimize system operation.

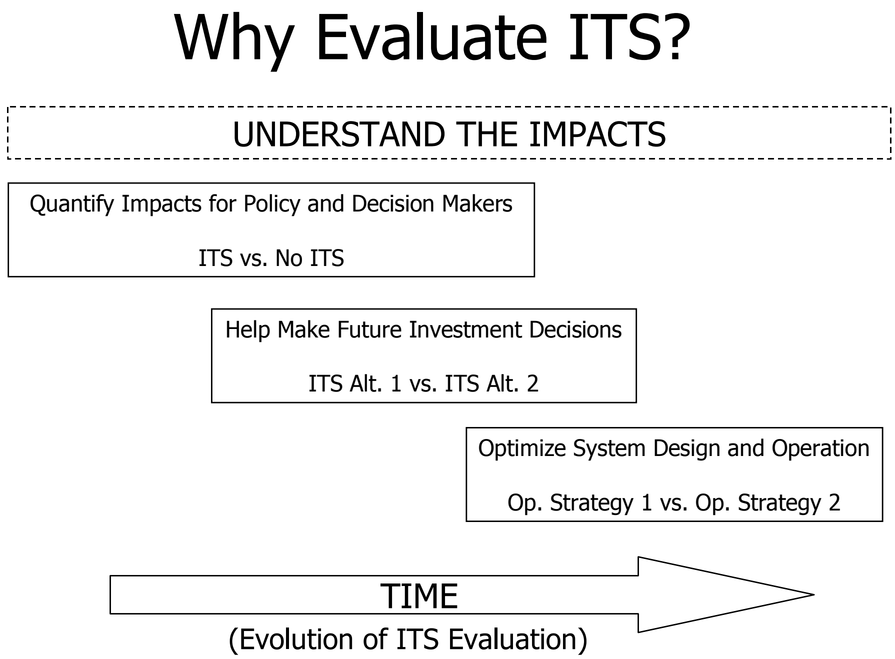


Figure 4. Evolution of ITS Evaluations (*4*).

GENERIC ITS EVALUATION FRAMEWORK

A generic, goals-based transportation evaluation framework is illustrated in Figure 5. This common method of evaluating complex transportation systems consists of measuring the progress or contribution toward stated transportation goals and objectives. The progress or contribution toward stated goals is quantified by selecting evaluation measures (a.k.a., metrics, measures of effectiveness (MOEs), performance measures) that directly relate to the goals and objectives.

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

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

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

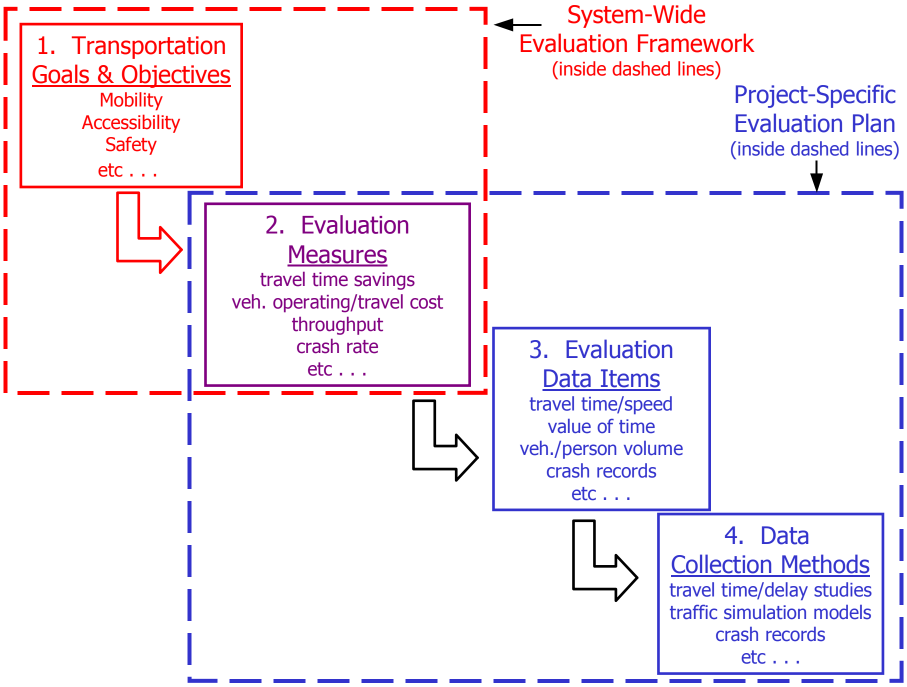


Figure 5. Goals-Based Transportation Evaluation (*4*).

An evaluation plan, as shown in Figure 5, is more project specific and is developed given specific ITS deployment plans and implementation details. The evaluation plan consists of the following:

- **Selection of specific evaluation measures** – select specific evaluation measures from the matrix of measures enumerated in the framework (i.e., measures are selected based on the ITS deployment's anticipated contribution toward the framework's goals).
- **Determination of evaluation data items** – identify data items that are necessary to calculate the selected evaluation measures.
- **Selection of data collection/estimation methods** – identify and select data collection and/or estimation methods that are necessary to support the needed evaluation data and measures.

The USDOT has applied a goals-based framework in the national ITS evaluation guidance developed thus far. For example, the *National ITS Program Plan* (*5*), which is designed to guide the development and deployment of ITS in the United States, presented six goals (shown below with supporting objectives) for the national ITS program:

1. Improve the safety of the nation's transportation system:
   - reduce number and severity of fatalities and injuries, and
   - reduce severity of collisions;
2. Increase the operational efficiency and capacity of the surface transportation system:
   - reduce disruptions due to incidents,
   - improve the level of service and convenience provided to travelers, and
   - increase roadway capacity;
3. Reduce energy and environmental costs associated with traffic congestion:
   - reduce harmful emissions per unit of travel, and
   - reduce energy consumption per unit of travel;
4. Enhance present and future productivity:
   - reduce costs incurred by fleet operators and others,
   - reduce travel time, and
   - improve transportation systems planning and management;
5. Enhance the personal mobility, convenience, and comfort of the surface transportation system:
   - provide access to pre-trip and en route information,
   - improve the security of travel, and
   - reduce traveler stress; and
6. Create an environment in which the development and deployment of ITS can flourish:
   - support the establishment of a significant U.S.-based industry for hardware, software, and services.

In developing the national ITS architecture, the USDOT developed metrics (or evaluation measures) that are related to these six ITS goals (*3*). Table 5 presents a matrix or "menu" of possible measures that can be used to evaluate ITS (i.e., ITS evaluations need not quantify every measure in this matrix). The ITS Joint Program Office of the USDOT advocates the use of what has been termed "a few good measures," which consist of a "few measures robust enough to represent the goals and objectives of the entire ITS program, yet are few enough to be affordable in tracking the ITS program on a yearly basis" (*3*). These "few good measures" are:

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

Table 5. ITS Benefits Matrix Based Upon USDOT'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 crashes number of security incidents exposure to crashes and incidents
Improve Safety	number of incidents number of crashes 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: USDOT, (1), p. 61

CHAPTER 3: TOOLS TO AID IN ESTIMATION OF BENEFITS

Because the traditional evaluation methods and planning models do not adequately represent many benefits derived from ITS applications, the quantification of ITS benefits and costs has been to date difficult. To assist public agencies and consultants in integrating ITS into the transportation planning process and evaluating potential benefits of ITS applications, several tools and software have been developed. These tools include Screening for ITS (SCRITS) and ITS Deployment Analysis System (IDAS). In this project, we have applied both SCRITS and IDAS to prepare benefit-cost analysis (BCA) and sensitivity analysis of some ITS packages in the Austin area. This chapter addresses these tools to aid in analysis and describes the pros and cons of each tool or aid.

EVALUATING ITS BENEFITS WITH IDAS

Principles of IDAS Model

Intelligent Transportation Systems Deployment Analysis System is a sketch-planning tool designed to assist transportation planners and ITS specialists with completing a comparative cost-benefit analysis for potential ITS projects. It can be used to estimate impacts, benefits, and costs attributed to deploying ITS components. IDAS is a post-planning tool that requires travel demand models to be processed before being imported. IDAS is also capable of implementing mode split and traffic assignment steps associated with the traditional model. IDAS is used to analyze alternatives, not to determine which ITS operations are optimal to use. For daily time period analysis, the induced/forgone demand option is available. IDAS is able to estimate various impacts including (*5*):

- changes in user mobility,
- travel time/speed,
- travel time reliability,
- fuel costs,
- operating costs,
- crash costs,
- emissions, and
- noise.

In IDAS, performance is given by market sector, facility type, and district. These modules, which correspond to different performance measures, are available for analyses (*5*):

- input/output interface module (IOM),
- alternatives generator module (AGM),
- benefits module,
- cost module, and
- alternatives comparison module.

Data Description

The following data are required inputs to IDAS:

- node coordinates, which include the node number, x-coordinate, and y-coordinate information of the nodes in the roadway network;
- link information, which includes the link ID, beginning node, end node, link length, facility type, number of lanes, capacity, traffic volume, and traffic speed;
- OD matrix, which contains the number of trips between each pair of zones; and
- left-turn penalty, which includes information about left-turn prohibition.

After importing these data to IDAS, the research team set up the roadway network. Then, the ITS options could be added to the roadway network, and the analysis could be conducted.

Besides these required data, there are also some user-defined data in IDAS. The user-defined inputs include types and quantities of equipment deployed, year of implementation and construction schedule, the cost of ITS equipment, and the discount rate. The cost module recognizes equipment-sharing opportunities (situations where different ITS components require identical equipment at similar locations), but the user selects the level of sharing. The other modules also provide inputs for the cost module. These include (5):

- alternative generator module and default data mainly,
- type of ITS equipment,
- quantity of equipment,
- location of deployment, and
- deployment schedule.

Benefit-Cost Analysis with IDAS

The benefit-cost analysis can be easily conducted after the required data are imported and the ITS options are added onto the road network in IDAS, because IDAS has two important modules: the benefits module and cost module. The benefits module within IDAS includes several submodules: travel time/throughput, emissions, energy, safety, and travel time reliability. To implement the calculation of benefits, the user needs to define the ITS options and run the benefit analysis. The IDAS cost module calculates the capital and operating costs of the various ITS deployments for both the public and private sectors. After a user has deployed and saved an ITS improvement, the cost module determines the equipment associated with the improvements and builds the annual stream of costs and average annual cost values for use in the benefit-cost analysis. The capital costs in IDAS also include construction and design costs. The cost module uses the inventory of equipment developed in the alternative generator module to calculate costs of the improvement (*5*).

EVALUATING ITS BENEFITS WITH SCRITS

Description of SCRITS Model

Screen for ITS was developed by Science Applications International Corporation (SAIC) under contract with the Federal Highway Administration for developing planning procedures for ITS applications. It was developed as a “first cut screening methodology” for analyzing benefits of various ITS applications and is not meant to be used for detailed analysis. The spreadsheet program is based on generic procedures that must be modified to represent specific situations (*6*).

SCRITS is compatible with various types of transportation analysis performed using other types of tools, such as travel demand models and simulation models. It is very flexible and can be used for analysis of different areas or regions. The results predicted by SCRITS are limited to daily effects. Some of its common uses include: approximation of user benefits for ITS strategic planning, approximation of user benefits for the evaluation of transportation alternatives for various types of studies, and sensitivity analysis of benefits of ITS applications with certain input assumptions (*6*).

SCRITS has the capability to analyze 16 different ITS applications, which include the following:

- closed circuit television (CCTV),
- detection,

- highway advisory radio (HAR),
- variable message signs (VMS),
- pager-based systems,
- kiosks,
- commercial vehicle operations (CVO) kiosks,
- traffic information over the Internet,
- automated vehicle location (AVL) systems for buses,
- electronic fare collection for buses,
- signal priority for buses,
- electronic toll collection,
- ramp metering,
- weigh-in-motion (WIM) systems,
- highway/rail grade crossing applications, and
- traffic signalization strategies.

These applications were chosen in the development based on prioritization of analysis needs and in evaluation of available information.

SCRITS only considers user benefits when determining the benefits associated with different ITS applications; it does not account for any benefits associated with agency operations. Although the measures of effectiveness vary by application, the primary measures include changes in: vehicle hours traffic (VHT), vehicle miles traveled (VMT), emissions (CO, NO_x, HC), vehicle operating cost, energy consumption, and the number of crashes. SCRITS uses these measures to calculate an economic benefit and benefit-to-cost ratio for most of the ITS applications (*6*).

Data for SCRITS

The analysis of a roadway segment using SCRITS requires the availability of the facility's baseline data. The data required for SCRITS analysis are:

- centerline miles of freeway,
- proportion of miles with shoulders on at least one side,
- weekday VMT,
- average weekday daily traffic (AWDT),

- capacity,
- ratio of AWDT to average annual daily traffic (AADT),
- recurring VHT,
- ratio of non-recurring VHT to recurring VHT,
- vehicle occupancy,
- cost of time (per person hour),
- average incident duration,
- freeway crashes per million VMT,
- percent of secondary freeway crashes of total crashes,
- average cost per crash, and
- discount rate.

Once the baseline data have been entered, it is possible to run analyses with SCRITS for different ITS deployments. With SCRITS, the research team tested three ITS options. They are variable message sign, closed circuit TV, and traffic detection. For each of these three ITS options, SCRITS requires different data. The data requirements for some evaluated ITS applications are listed below.

To complete the analysis for VMSs, the following data are required:

- average volume per hour past sign,
- number of times per day each sign provides incident information,
- time sign is active for each incident,
- percent of drivers (vehicles) passing sign that save time,
- amount of time saved by each passing vehicle,
- installation cost,
- service life, and
- annual operating/maintenance cost.

The analysis for closed circuit TV requires the following data:

- percent CCTV coverage on freeway before improvement,
- percent CCTV coverage on freeway after improvement,
- estimated reduction in average incident duration,
- savings in VMT per weekday,

- installation cost,
- service life, and
- annual operating cost.

The analysis for traffic detection requires the following data:

- percent CCTV coverage on freeway before improvement,
- percent CCTV coverage on freeway after improvement,
- estimated reduction in average incident duration,
- savings in VMT per weekday,
- installation cost,
- service life, and
- annual operating/maintenance costs.

Break-Even Analysis with SCRITS

To conduct a true benefit-cost analysis in a specific location, the detailed before-and-after data on the actual performance of the project are required. However, the actual performance data after the deployment of the project are unavailable during the stage of ITS planning and project design. Break-even analysis provides a method to determine the minimum level of performance necessary for a project to have equivalent benefits and costs. With break-even analysis, the critical performance variables affecting the ITS benefits could be identified. Also, given an acceptable benefit-cost ratio, the relative magnitude of these variables can be determined. The break-even analysis can be useful because the results can be interpreted to see if they are achievable or not.

The process of doing a break-even analysis with SCRITS is straightforward. Basically, the benefit-cost equations are solved backward by assuming that the benefit-cost ratio equals 1. The annual benefits of an ITS option are set equal to the total annual cost. The results solved from the benefit-cost equations are usually in terms of performance measures such as reduction of travel time, reduction of vehicle miles traveled, or reduction of crash rate. The critical performance measures can be identified for further use in sensitivity analysis. By varying the performance measures, their impact on the break-even point can be identified.

THE APPLICATIONS OF IDAS AND SCRITS FOR ITS BENEFITS ASSESSMENT

Case Study One: Assessing the Benefits of ITS Components and Integrated ITS Applications

This section presents the methodology of the study and the findings for a freeway corridor model drawn from the highway network west of downtown Austin, Loop 1/Mopac. The work was completed with the IDAS Build II package. Despite the limitations of this package, we were able to assess a number of different ITS technologies including freeway traffic management system (FTMS), incident management system (IMS), and advanced traveler information system (ATIS). Of particular interest to this project are the benefit-cost analysis and the quantification of likely operational impacts from ITS components (FTMS, IMS, and ATIS) or integrated control between the isolated ITS components and combinations.

We undertook a set of experiments to assess the net benefits of ITS applications along the Loop 1 corridor, from RM 2244 to Far West Blvd. The purpose of this set of experiments was to test the actual ITS applications existing on this corridor, as well as to estimate the impact and benefits of some potential ITS applications.

Experimental Program

In this project, three ITS subsystems have been evaluated in isolation and combination. These subsystems are FTMS, IMS, and Regional Multimodal Traveler Information System. Five isolated ITS options were evaluated with IDAS:

- centralized ramp metering system,
- combination of incident detection and response system,
- highway advisory radio,
- dynamic message sign on freeway, and
- in-vehicle centralized route guidance system.

These ITS options have not been deployed on Loop 1 yet. However, by evaluating these ITS options with the IDAS model, the potential impact and benefits of these ITS options can be estimated.

Figure 6 presents a small sample of the network configuration.

In order to assess the impact of ITS applications, the data from the travel demand model acquired from the Capital Area Metropolitan Organization (CAMPO) are used in this project. The year of analysis is 2007, and the base year for the data is 1997.

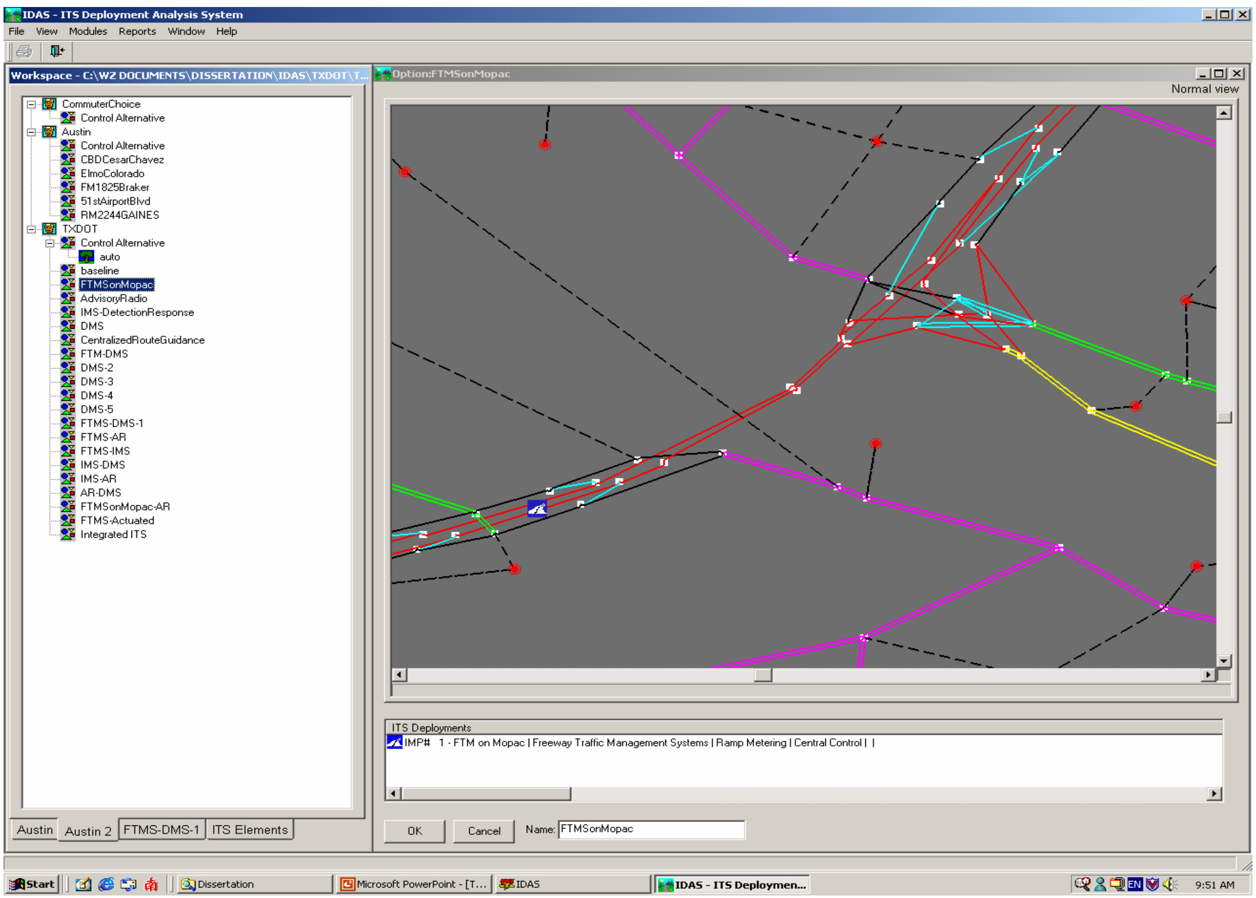


Figure 6. A Small Part of the Austin Roadway Network in IDAS.

FTMS Experiment

The centralized ramp metering system was evaluated as the ITS option of the freeway Traffic Management System. The experiment was based on the following hypothesis: the deployment of ramp metering along Loop 1 improves corridor throughput and efficiency.

Experimental Controls: The FTMS experiment attempts to estimate the possible impact if ramp meters were deployed on every entrance ramp along Loop 1 from RM 2244 to Far West Blvd. in both directions.

TIS Experiment

Highway advisory radio, dynamic message signs on the freeway, and an in-vehicle centralized route guidance system were tested as the ITS options of Regional Multimodal Traveler Information System. The experiment was based on the following hypothesis: the provision of primarily pre-trip and real-time traveler information services containing more accurate, frequently updated real-time traffic information on roads reduces overall travel delay and fuel consumption, and it improves system throughput, travel time reliability, and user's travel mobility.

Experimental Controls: The Traveler Information System (TIS) experiment attempts to capture the projected near-term impacts on Loop 1 from the utilization of various traveler information services such as highway advisory radio, dynamic message signs on the freeway, and an in-vehicle centralized route guidance system. The traveler information services provide incident, construction, and emergency road closure information through highway advisory radio, dynamic message signs, and a centralized route guidance system. In the baseline case, in which no traveler information service is supplied, travelers make route choice decisions under greater uncertainty about the delays associated with incidents, recurrent bottlenecks, or weather factors. With the deployment of TIS, travelers make route choice decisions with less uncertainty because the traffic information and possible delays are delivered to the road users.

IMS Experiment

The combination of incident detection and response was tested as the ITS option for the incident management system. This experiment was conducted based on the following hypothesis: with the deployment of the incident detection and response system and the consequent reduction of the incident duration, the user's mobility and travel time reliability are improved.

Experimental Controls: The relevant devices and services for incident detection and response include CCTVs, loop detectors on road and ramp, information processing and delivery, and emergency operations center coordination. The response to an incident on the road is characterized by incident information collection time, reaction time, and the time to remove the incident. In this experiment, we assume that loop detectors and CCTVs are deployed on Loop 1 along the section from RM 2244 to Far West Blvd. We assume that there is some reduction in incident duration due to the quicker detection, response, and increased coordination among responding agencies.

Integrated ITS Alternatives Experiments

The experiments are conducted using the following hypothesis: implementing the integrated deployments by combining FTMS, TIS, and IMS applications improves the user's mobility and travel time reliability, and it reduces the negative impacts of traffic on the environment.

Experimental Controls: The integrated ITS alternatives are prospective ITS deployments consisting of the combinations of FTMS, TIS, and IMS. In this project, we tested the integration of freeway traffic management system with traveler information system, the integration of incident management system with traveler information system, and the integration of traveler information system with incident management system, respectively. The following experiments on integrated ITS alternatives were completed:

- the integration of FTMS and TIS, which features a combination of ramp metering and dynamic message sign deployments on Loop 1;
- the integration of TIS and IMS, which contains two integrated ITS alternatives;
    - a combined deployment of incident detection and response system and highway advisory radio on Loop 1; and
    - a combined deployment of incident detection and response system with dynamic message sign; and
- the integration of IMS and FTMS, which features a combination of ramp metering system and incident detection and response system on Loop 1.

Experiment Results and Findings

The experimental results are listed in Table 6 through Table 10.

The results in Table 6 show that the centralized ramp metering system, highway advisory radio, and dynamic message sign will bring positive net benefits if they are deployed on Loop 1.

The ramp metering system has a benefit-cost ratio of 6.38. From the performance summary, the reader can see that with the deployment of ramp meters on Loop 1, the daily VHT in the Austin area is reduced by 1407 hours (0.1 percent timesaving); personal hours of travel are reduced by 1829 hours (0.1 percent time saving); emission is reduced by 0.1 percent; and crash rate is reduced by 0.4 percent. Considering that the improvements are calculated based on the whole network level, the benefits of ramp metering on Loop 1 are significant.

The highway advisory radio has a benefit-cost ratio of 16.47, which is higher than the other ITS options. As a traveler information service, the cost of HAR is low, while the benefits of HAR are significant. This difference explains why the benefit-cost ratio of HAR is higher than the other ITS options.

The dynamic message sign also has a high benefit-cost ratio of 5.78. With the deployment of DMS, the user mobility is improved greatly. From Table 6 the reader can see that the major benefits of DMS come from the change of user mobility. On the other hand, the annual cost of DMS is relatively low compared to other ITS options.

The incident detection and response system shows negative net annual benefits. Its benefit-cost ratio is less than 1, which is 0.91. Considering that we assume the incident detection and response system works only on weekdays and the incident duration reduction is 20 percent, which is conservative, the incident detection and response system is still a good ITS option to improve the freeway operation.

When combining these ITS components, the integrated systems still show positive net benefits. New benefit-cost ratios vary between the benefit-cost ratios of the separated ITS components. The total benefits and costs are always the summation of the separated ITS options. However, when combining the freeway traffic management system with the dynamic message sign, there exist some extra benefits that make the benefit-cost ratio higher than either of these two ITS components if deployed separately. The experimental results are shown in Table 7.

Table 6. Benefit-Cost Analysis of Isolated ITS Options.

Benefit-Cost Summary

Project: Austin 2

Benefits are reported in 1995 dollars

Annual Benefits	Weight	FTMS* on Mopac	Highway Advisory Radio	IMS** Detection & Response	DMS***	In-Vehicle Centralized Route Guidance (GPS)
Change in User Mobility	1.00	$ (2,154,634)	$ 2,066,213	$ (0)	$ 302,856	$ 2,156
Change In User Travel Time						
Travel Time Reliability	1.00	$ 8	$ (0)	$ 7	$ (0)	$ (0)
Change in Costs Paid by Users						
Fuel Costs	1.00	$ 743,589	$ (0)	$ 516,373	$ (0)	$ (0)
Non-fuel Operating Costs	1.00	$ 429,978	$ (0)	$ (0)	$ (0)	$ (0)
Crash Costs (Internal Only)	1.00	$ 2,685,866	$ (0)	$ 133,778	$ (0)	$ (0)
Change in External Costs						
Crash Costs (External Only)	1.00	$ 473,970	$ (0)	$ 23,608	$ (0)	$ (0)
Emissions						
HC/ROG	1.00	$ 31,902	$ (0)	$ 23,799	$ (0)	$ (0)
NOx	1.00	$ 84,949	$ (0)	$ 62,690	$ (0)	$ (0)
CO	1.00	$ 315,829	$ (0)	$ 187,037	$ (0)	$ (0)
Noise	1.00	$ 1,892	$ (0)	$ (0)	$ (0)	$ (0)
Total Annual Benefits		**$ 2,613,347**	**$ 2,066,213**	**$ 947,291**	**$ 302,856**	**$ 2,156**

Annual Costs						
Average Annual Private Sector Cost		$ 0	$ 0	$ 0	$ 0	$ 930,951
Average Annual Public Sector Cost		$ 409,748	$ 125,480	$ 1,046,064	$ 52,353	$ 541,809
Total Annual Cost		**$ 409,748**	**$ 125,480**	**$ 1,046,064**	**$ 52,353**	**$ 1,472,760**

Benefit-Cost Comparison						
Net Benefit (Annual Benefit-Annual Cost)		$ 2,203,600	$ 1,940,733	$ (98,773)	$ 250,503	$ (1,470,604)
B-C Ratio (Annual Benefit-Annual Cost)		6.38[1]	16.47[2]	0.91[3]	5.78[4]	0.00[5]

Note: Notes for Table 6:
*: FTMS—Freeway Traffic Management System. In IDAS, ramp metering is the major deployment for FTMS.
**: IMS—Incident Management System.
***: DMS—Dynamic Message Sign.
[1]—The benefit-cost ratio is calculated based on the following assumptions:

- Deployment impacts value on ramp:
    - Capacity Change: -50%;
    - Crash Rate Reductions: 25% on fatality, injury, and property damage.
- Deployment impacts value on freeway:
    - Capacity Change: +15%;
    - Crash Rate Reductions: 20% on fatality, injury, and property damage.

[2]—The benefit-cost ratio is calculated based on the following assumptions:

- Percent vehicles tuned to broadcast: 25%;
- Percent of drivers hearing broadcast that save time: 15%;

[3]—The benefit-cost ratio is calculated based on the following assumptions:

- Incident duration reduction: 20%;
- Fuel consumption reduction: 10%;
- Crash rate reduction on fatality: 10%;
- Emission rate reductions: 10% on CO, HC/ROG, $NO_{x,}$ and PM.

[4]—The benefit-cost ratio is calculated based on the following assumptions:

- Percent vehicles passing sign that save time: 5.0%;
- Percent time the sign is turned on and disseminating information: 80%;
- Average amount of time savings (min): 1 minute.

[5]—The benefit-cost ratio is calculated based on the following assumptions:

- Number of vehicles equipped with in-vehicle global positioning system (GPS): 1000;
- Market penetration: 1.4%;
- With system turned on: 50%.

All the benefits in the table are calculated based on the assumption that the number of periods per year is 247.

Table 7. Benefit-Cost Summary: Integration of FTMS (Ramp Metering) and TIS (DMS).

Annual Benefits	**Weight**	**FTMS**	**TIS**	**FTMS+TIS**
Change in User Mobility	1.00	-2,838,270	398,948	-2,084,300
Change in User's Costs				
Fuel Costs	1.00	979,519	0	979,519
Non-Fuel Operating Costs	1.00	566,404	0	566,404
Internal Crash Costs	1.00	3,538,054	0	3,538,054
Change in External Costs				
External Crash Cost	1.00	624,354	0	624,354
Emissions				
HC/ROG	1.00	42,024	0	42,024
NOx	1.00	111,902	0	111,902
CO	1.00	416,037	0	416,037
Noise	1.00	2,492	0	2,492
Total Annual Benefits		**3,442,526**	**398,948**	**4,196,496**
Total Annual Cost		**539,755**	**68,963**	**608,718**
Benefit-Cost Comparison				
Net Benefit		**2,902,771**	**329,985**	**3,587,778**
B-C Ratio		**6.38**	**5.78**	**6.91**

Note: Benefits and costs are reported in 2001 dollars.

When the combination of ramp metering and dynamic message sign is deployed on Loop 1, the net annual benefit becomes higher compared to the individual application of ramp metering and DMS. From the experimental results, we found that with the deployment of DMS, the loss of user's mobility caused by ramp metering was reduced by 26.6 percent. Also, from the viewpoint of economic efficiency, the combination of ramp metering and DMS has a higher benefit-cost ratio of 6.91, which is higher than the benefit-cost ratios when using ramp metering and dynamic message signs separately. Therefore, the integration of ramp metering and dynamic message signs is recommended for Loop 1.

Table 8. Benefit-Cost Summary: Integration of IMS (Incident Detection and Response) and TIS (Highway Advisory Radio).

Annual Benefits	**Weight**	**IMS**	**TIS**	**IMS+TIS**
Change in User Mobility	1.00	0	2,721,794	2,721,794
Change in User's Costs				
Fuel Costs	1.00	516,373	0	680,210
Internal Crash Costs	1.00	133,778	0	176,224
Change in External Costs				
External Crash Cost	1.00	23,608	0	31,098
Emissions				
HC/ROG	1.00	23,799	0	31,350
NOx	1.00	62,690	0	82,580
CO	1.00	187,037	0	246,382
Total Annual Benefits		**947,291**	**2,721,794**	**3,969,647**
Total Annual Cost		**1,046,064**	**165,293**	**1,544,677**
Benefit-Cost Comparison				
Net Benefit		**-130,112**	**2,556,501**	**2,424,969**
B-C Ratio		**0.91**	**16.47**	**2.57**

Note: Benefits and costs are reported in 2001 dollars.

When the incident detection and response system is deployed with highway advisory radio, the road user's benefits on fuel cost and crash cost increase by 32 percent compared to deploying the incident detection and response only. The overall benefits on emissions also increase significantly by 31.7 percent compared to the incident detection and response system itself. On the other hand, the overall benefit-cost ratio of the combination of incident detection and response and the highway advisory radio is 2.57, which is higher than the benefit-cost ratio of incident detection and response system only (0.91) and lower than the highway advisory radio only (16.47). The integrated deployment of incident detection and response and the highway advisory radio shows the economic efficiency.

Table 9. Benefit-Cost Summary: Integration of IMS (Incident Detection and Response) and TIS (Dynamic Message Sign).

Annual Benefits	Weight	IMS	TIS	IMS+TIS
Change in User Mobility	1.00	0	398,948	398,488
Change in User's Costs				
Fuel Costs	1.00	516,373	0	680,210
Internal Crash Costs	1.00	133,778	0	176,224
Change in External Costs				
External Crash Cost	1.00	23,608	0	31,098
Emissions				
HC/ROG	1.00	23,799	0	31,350
NOx	1.00	62,690	0	82,580
CO	1.00	187,037	0	246,382
Total Annual Benefits		**947,291**	**398,948**	**1,646,342**
Total Annual Cost		**1,046,064**	**68,963**	**1,446,928**
Benefit/Cost Comparison				
Net Benefit		**-130,112**	**329,985**	**199,413**
B-C Ratio		**0.91**	**5.78**	**1.14**

Note: Benefits and costs are reported in 2001 dollars.

The idea of integrating the incident detection and response system with the dynamic message sign is to test if the combination of these two ITS options can generate more benefits to the road users. The experimental results indicate that the combination of incident detection and response system and DMS has a more positive impact on the user's fuel cost, crash cost, and emissions. Compared to the deployment of incident detection and response system alone, the combined ITS deployment generates 32 percent more benefits on the fuel cost, crash cost, and emissions. The overall benefits increase by 74 percent while the overall costs increase by 38 percent. The benefit-cost ratio of the combined incident detection and response system and the DMS is 1.14, which shows the economic efficiency of the combination of incident detection and response system with DMS.

Table 10. Benefit-Cost Summary: Integration of FTMS (Ramp Metering) and IMS (Incident Detection and Response).

Annual Benefits	Weight	FTMS	IMS	FTMS+IMS
Change in User Mobility	1.00	-2,838,270	0	-6,050,765
Change in User's Costs				
Fuel Costs	1.00	979,519	516,373	238,088
Non-Fuel Operating Costs	1.00	566,404	(0)	137,309
Internal Crash Costs	1.00	3,538,054	133,778	2,639,314
Change in External Costs				
External Crash Cost	1.00	624,354	23,608	465,756
Emissions				
HC/ROG	1.00	42,024	23,799	-15,194
NOx	1.00	111,902	62,690	22,406
CO	1.00	416,037	187,037	-248,346
Noise	1.00	2,492	0	-15,225
Total Annual Benefits		**3,442,526**	**947,291**	**-2,826,651**
Total Annual Cost		**539,755**	**1,046,064**	**1,917,720**
Benefit-Cost Comparison				
Net Benefit		**2,902,771**	**-130,112**	**-4,744,370**
B-C Ratio		**6.38**	**0.91**	**-1.47**

Note: Benefits and costs are reported in 2001 dollars.

An experiment on the integration of FTMS (central control ramp metering) and IMS (incident detection and response) was conducted in this project. However, a negative benefit-cost ratio was obtained. According to the experimental results, the main loss of benefits is the change in user mobility. This loss might happen if the ramp meters were used to shut down the entrances to the freeway when an incident occurred and was detected by the incident detection and response system. If the entrances to the freeway were closed by ramp meters, then the vehicles on the frontage roads and ramps had to wait for the clearance of the incident or switch to other routes. In this case, the user's mobility and the benefits on fuel cost, crash cost, and emissions will be reduced significantly.

Case Study Two: Development of an ITS Framework for Congestion Pricing

A case study was performed by Ms. Colleen Michaela McGovern to develop an ITS framework for congestion pricing (*7*). The Austin transportation network was used to perform the study. The analysis used the two tools IDAS and SCRITS. The study helped in comparing and contrasting the working of these two software tools that can be used for ITS sketch planning. It also gave an insight into the capabilities and limitations of each of these tools, as well as their data requirements for performing an analysis.

The corridor selected for implementation of the congestion-pricing scheme was the US 183 freeway segment in Austin, Texas, between McNeil Road and IH-35. This corridor was selected because it is the major east-west connector in the city, and there are no comparable alternate connectors. It was believed that the congestion-pricing framework would be effective on such a corridor that does not have any alternate routes. The ITS elements deployed on the corridor for the implementation of the scheme were:

- 21 variable message signs, one at each entry ramp;
- 20 CCTV cameras for monitoring the traffic at a spacing of about 0.9 miles; and
- 34 loop detectors at a spacing of 0.5 mile.

Four scenarios were studied. These were the:

- camera alternative,
- detection alternative,
- traffic management center alternative, and
- combined alternative.

In the first three scenarios only one ITS component was deployed, and its effects were studied. In the last alternative the effects of having a combined deployment of all the elements were studied.

To study the effects of the deployments, sensitivity and break-even analysis were performed. These analyses performed with these two software tools helped in comparing the different scenarios. IDAS was really helpful in this regard as it integrated all the different operational impacts of these deployments into benefits and costs. Hence, seemingly different deployments could be compared by measuring the benefit-cost ratio.

Case Study Three: An Assessment of ITS and the Impact of Transportation Control Measures

As the value of protecting the environment and reducing the direct negative impact that poor air quality has on people's health develops, so too does the prospect for intelligent transportation systems, in conjunction with transportation control measures (TCMs), to help prevent environmental degradation. This combination leads to a cost-effective alternative to building new roads. Current policies and funding procedures pose an economic risk on regions with poor air quality. Likewise, society encounters a greater risk due to the negative impacts of air pollution. This assessment shows how IDAS uses performance measures that are typically not taken into account in a benefit-cost analysis, such as emissions, energy consumption, noise, and safety, to generate risk analysis graphs and road network graphics that can be used to evaluate ITS deployments.

First, the congestion problem in Austin, Texas, is identified in this study. Since there are limited funds and limited land, building more roads to alleviate the congestion problem is no longer a feasible solution. Intelligent transportation systems, however, serve as a possible alternative. In this project, the ITS architecture is described in order to show how and where freeway management systems, including ramp metering, closed circuit television, and loop detectors, fit. Several studies conducted all over the United States and Canada were described. Typically, these studies show that there is potential for ITS to reduce emissions. However, benefit-cost methodologies that account for benefits for society or the private sector, as opposed to the traditional method of calculating user benefits, are rare. As a result, high capital costs involved in deploying new technologies may impede certain key ITS architecture components from being implemented in practice.

Next, the transportation control measures were described in this project. The impacts of TCMs are quantified by the Environmental Protection Agency's (EPA's) COMMUTER Model. The results of alternative work schedules and employer support programs showed that unless the Austin region makes a major commitment, TCMs have a minimal impact on the system. A major commitment could mean not only improving pre-existing programs or implementing new programs at a higher level, but also land use improvements, transit operations, and pricing incentives or disincentives to manage congestion.

Finally, a risk assessment has shown the impact that ITS technologies in the Transportation Improvement Program (TIP) 2002 authorization could have on the Austin region. Two deployments, Gaines Creek and Braker Lane, showed definite benefits. However, the other four deployments had benefit-cost ratios less than one. When the benefit-cost ratios were computed so that the changes in emissions due to TCMs were reflected, minimal differences in benefit-cost ratios were observed. On the more favorable side, the net loss was reduced when TCMs were implemented. When a risk assessment was conducted, the six ITS deployments changed in order of priority. Even Airport Boulevard, which had a benefit-cost ratio of zero, moved up in ranking. This result shows that the value of ITS benefits in emissions reductions cannot depend solely on benefit-cost ratios.

COMPARISON OF THE SOFTWARE TOOLS IDAS AND SCRITS

Although both SCRITS and IDAS are sketch planning tools for ITS applications, there are many differences in their capabilities and necessary data inputs. IDAS has the capability to analyze many more ITS deployments compared to SCRITS, and it is also capable of analyzing benefits over different time periods, while SCRITS can compute only daily or weekly benefits. In addition, IDAS has the capability to directly analyze the effects of using various ITS deployments in combination, which SCRITS is unable to do. With SCRITS it is up to the analyst to determine a way to collectively analyze multiple ITS deployments.

The necessary data for analysis with IDAS are much more extensive than the data needed to run analysis with SCRITS. In evaluating the benefits of each ITS deployment, IDAS uses information specific to each link in a corridor, while SCRITS can only evaluate based on corridor level information. In addition the user must determine the location of each ITS component being deployed when using IDAS, but SCRITS only requires the number of each ITS component.

The results of IDAS are also much more specific than that of SCRITS. SCRITS only breaks down the benefit results into annual time savings and annual savings in vehicle operating costs. In IDAS, on the other hand, the benefits are broken down to four main categories which include: change in user mobility, change in user travel time, change in costs paid by users, and change in external costs. Most of these are broken down even further with more specific information. In addition, IDAS is capable of predicting the benefits associated with changes in public agency costs, while SCRITS is only capable of predicting benefits associated with changes in user costs.

SUMMARY AND RECOMMENDATIONS

Summary

In this project, the IDAS model and the SCRITS model are the major analysis tools used. Some auxiliary tools such as TransCAD and COMMUTER model were used to aid analysis.

The current and potential ITS deployments were tested in the Austin area with these tools. The analysis shows that ITS deployments like freeway traffic management systems, traveler information systems, and incident management systems show economic efficiency. These ITS deployments can bring significant potential benefits to travelers' mobility, travel time reliability, safety, and the environment. The integration of different ITS deployments were tested in this project. Some integrated ITS deployments show economic efficiency, while others do not. The purpose of such examination is to test the interrelationship of different ITS options. The interrelationship between different ITS options could be independent and complementary. With the tests of different integrated ITS alternatives, the alternative or combination has better performance and more benefits can be identified.

Using these tools, researchers conducted an investigation of ITS framework for congestion pricing. The potential benefits of ITS application for congestion pricing were estimated. The results of break-even analysis and sensitivity analysis are useful to identify the critical performance measures of the ITS deployments. Also, an assessment of ITS and the impact of transportation control measures was conducted in this project. A methodology to identify the priority of ITS deployments was developed in this project.

Recommendations

Based on the experience and findings of using some tools to aid in analysis in this project, we make the following recommendations:

- Traveler information systems, freeway management systems, and incident management systems should receive priority to be deployed because they can bring significant benefits to travelers.

- More ITS benefits reports should be collected and reviewed to expand the ITS benefits database.
- The dynamic traffic assignment simulation tool needs to be introduced to ITS planning and evaluation.
- Additional efforts are needed to estimate the impact of ITS and congestion pricing or other TCMs on emissions.
- A methodology for ITS alternatives selection and implementation plan is necessary.

CHAPTER 4: METHODOLOGY FOR ESTIMATING THE BENEFITS OF ITS MARKET PACKAGES

DESCRIPTION OF APPROACH

This chapter presents a generic approach for conducting meaningful evaluations. The methodology is detailed enough to provide technical guidance, yet general enough to apply to existing and future market packages and user services, and can incorporate new tools and revised estimates of benefits.

The proposed evaluation process is structured around ITS market packages, a fundamental unit of the national ITS architecture that provides a service-oriented perspective. Analytical evaluation guidance is provided within this report for 28 of the 75 defined market packages. Table 11 lists the market packages addressed, as well as those not included in this guide. The market packages selected represent the most common applications currently employed by TxDOT and those likely to be employed in the near future.

For each market package, an "evaluation tree" was devised to guide the end user through an evaluation process founded on goals, objectives, and customers or direct beneficiaries. The evaluation tree concept was adapted from research conducted by the University of Wisconsin (*8*). The value of the tree structure is that it depicts the way in which ITS benefits travelers, non-travelers, freight customers, agencies, and society as a whole, and it graphically illustrates the link between the customer and objectives, which can then be evaluated using a variety of measures. Figure 7 illustrates the basic structure of each tree.

Table 11. Market Packages Selected for Detailed Evaluation Guidance.

Included in Evaluation	Not Included in Evaluation
ATMS01 Network Surveillance	APTS1 Transit Vehicle Tracking
ATMS02 Probe Surveillance	APTS2 Transit Fixed-Route Operations
ATMS03 Surface Street Control	APTS3 Demand Response Transit Operations
ATMS04 Freeway Control	APTS4 Transit Passenger and Fare Management
ATMS05 HOV Lane Management	APTS5 Transit Security
ATMS06 Traffic Information Dissemination	APTS6 Transit Maintenance
ATMS07 Regional Traffic Control	ATIS2 Interactive Traveler Information
ATMS08 Incident Management System	ATIS3 Autonomous Route Guidance
ATMS10 Electronic Toll Collection	ATIS4 Dynamic Route Guidance
ATMS13 Standard Railroad Grade Crossing	ATIS5 ISP Based Route Guidance
ATMS18 Reversible Lane Management	ATIS6 Integrated Transportation Management/Route Guidance
APTS7 Multi-Modal Coordination	ATIS7 Yellow Pages and Reservation
APTS8 Transit Traveler Information	ATIS8 Dynamic Ridesharing
ATIS1 Broadcast Traveler Information	ATIS9 In-vehicle Signing
CVO03 Electronic Clearance	ATMS09 Traffic Forecast & Demand Management
CVO04 CV Administrative Processes	ATMS11 Emissions Monitoring & Management
CVO05 International Border Electronic Clearance	ATMS12 Virtual TMC & Smart Probe Data
CVO06 Weigh-in-Motion	ATMS14 Advanced Railroad Grade Crossing
CVO07 Roadside CVO Safety	ATMS15 Railroad Operations Coordination
EM1 Emergency Response	ATMS16 Parking Facility Management
EM2 Emergency Routing	ATMS17 Regional Parking Management
EM4 Roadway Service Patrols	ATMS19 Speed Monitoring
AD1 ITS Data Mart	ATMS20 Drawbridge Management
AD2 ITS Data Warehouse	AVSS01 Vehicle Safety Monitoring
AD3 ITS Virtual Data Warehouse	AVSS02 Driver Safety Monitoring
MC03 Road Weather Data Collection	AVSS03 Longitudinal Safety Warning
MC04 Weather Information Processing & Distribution	AVSS04 Lateral Safety Warning
MC08 Work Zone Management	AVSS05 Intersection Safety Warning
	AVSS06 Pre-Crash Restraint Development
	AVSS07 Driver Visibility Improvement
	AVSS08 Advance Vehicle Longitudinal Control
	AVSS09 Advance Vehicle Lateral Control
	AVSS10 Intersection Collision Avoidance
	AVSS11 Automated Highway System
	CVO01 Fleet Administration
	CVO02 Freight Administration
	CVO08 On-board CVO Safety
	CVO09 CVO Fleet Maintenance
	CVO10 HAZMAT Management
	EM3 Mayday Support
	MC01 Maintenance & Construction Vehicle Tracking
	MC02 Maintenance & Construction Vehicle Maintenance
	MC05 Roadway Automated Treatment
	MC06 Winter Maintenance
	MC07 Roadway Maintenance & Construction
	MC09 Work Zone Safety Monitoring
	MC10 Maintenance & Construction Activity Coordination

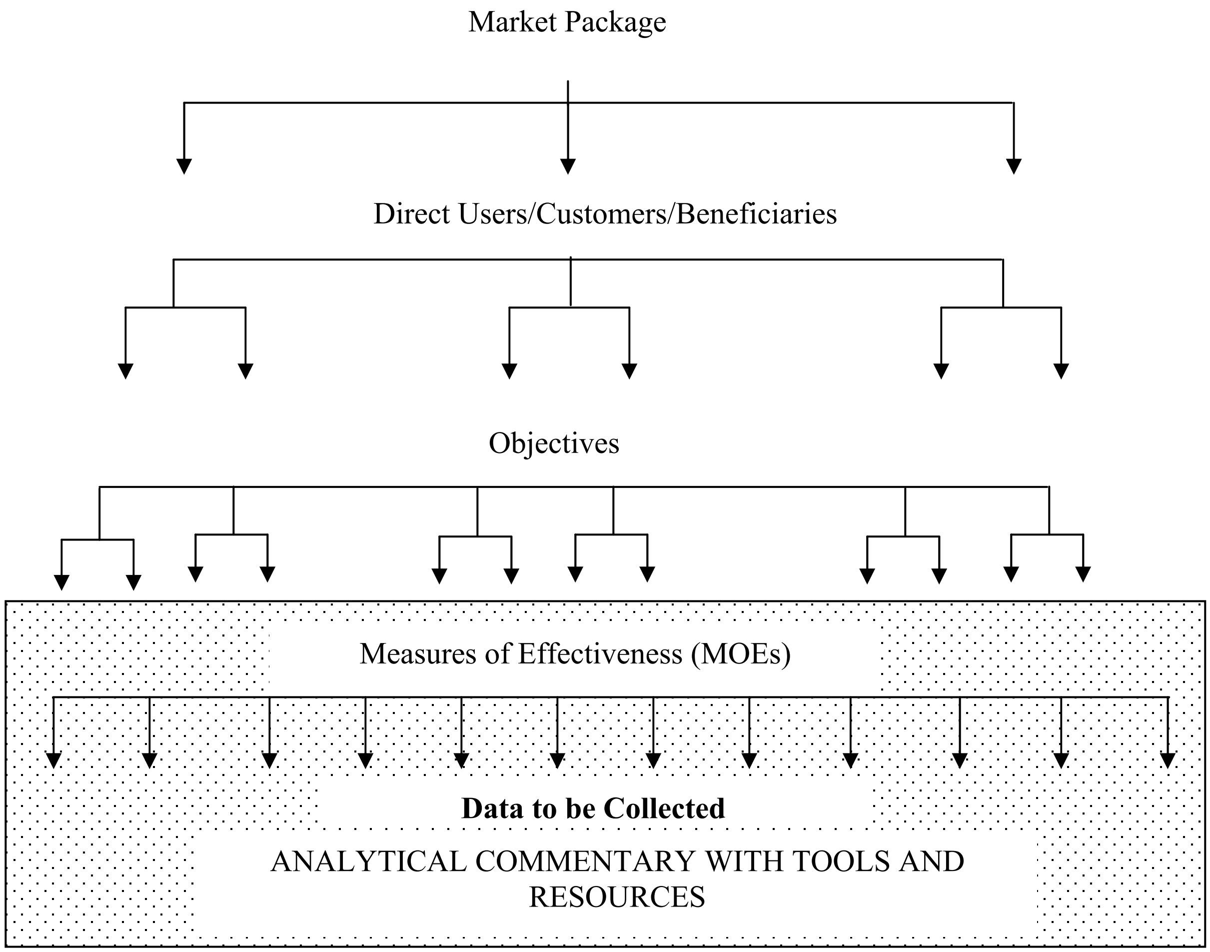


Figure 7. Generic Structure of Evaluation Tree.

Evaluation Process

The steps in the evaluation process are represented in the flowchart in Figure 8. Each step in the process is described below.

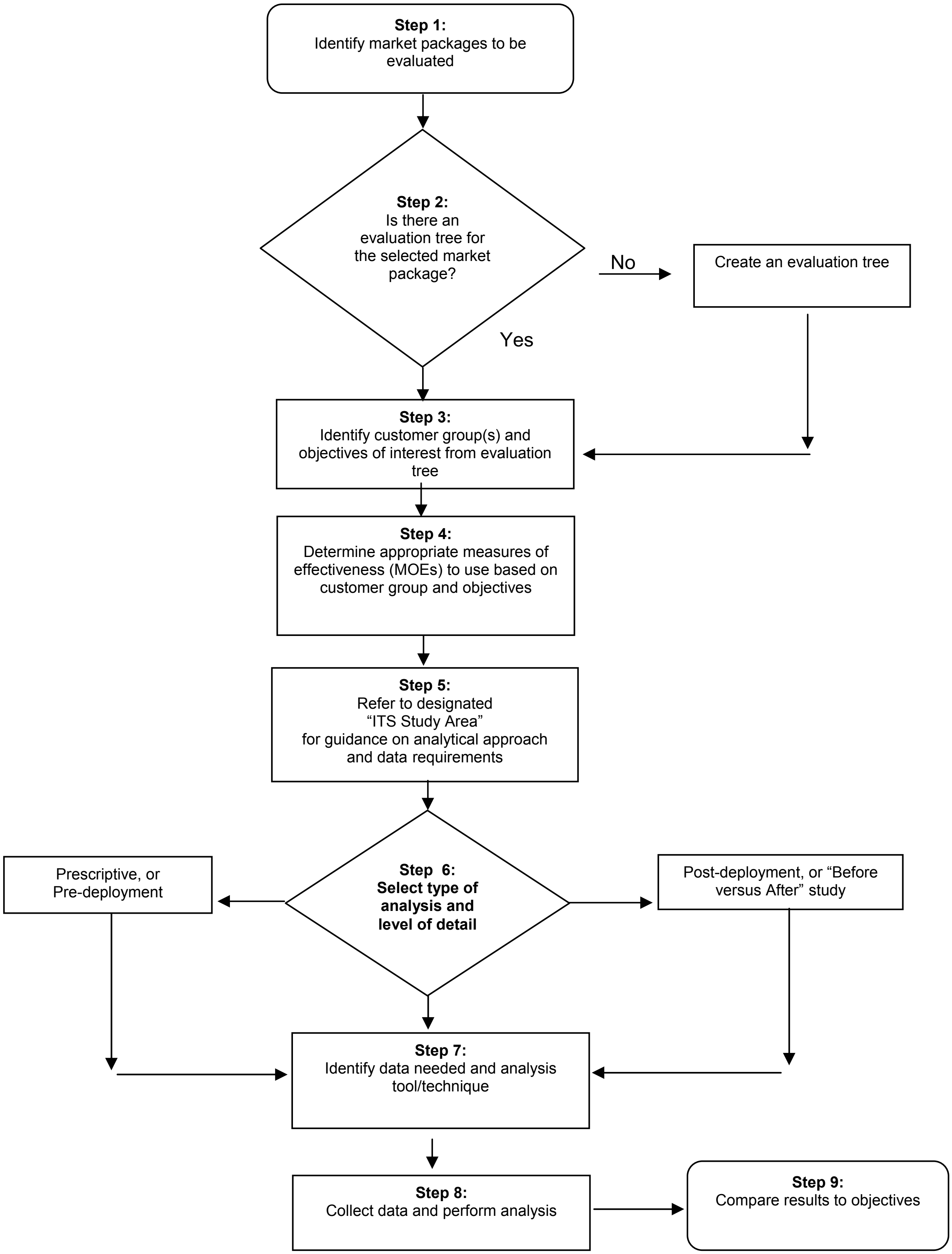


Figure 8. ITS Benefits Evaluation Process.

Step 1. Identify Market Packages

This initial step is self-explanatory. The market package is selected based on the ITS application and what the application is intended to achieve. The selected menu of market packages is shown in Table 12. The table lists the contribution of each market package to the Texas transportation goals.

Step 2. Use Evaluation Trees for Selected Market Packages

As part of this project, evaluation trees have been developed for the following ITS market packages shown in Table 12.

These market packages and their evaluation trees are individually described in Appendix A. For market packages not represented above, the evaluator can create a market package evaluation tree using selected references available through the research project's ITS benefits website at http://tti.tamu.edu/austin/its (*8*, *9*, *10*).

Step 3. Select Pertinent Customer Groups and Objectives

Many traditional ITS benefit analyses have concentrated mainly on transportation user benefits, such as total delay, travel time and speed, or number and severity of crashes. In reality, however, there are several other groups or subgroups that are impacted or affected by the implementation of ITS. These groups, the benefits or impacts to whom should be considered in ITS evaluations, include the following: (*10*)

- various traveler groups (e.g., urban, rural, suburban, elderly, commuters, etc.);
- non-travelers (e.g., freight customers, residents, property and business owners);
- private-sector operators and industry (e.g., trucking, hardware/software manufacturers, travel information service providers, media);
- public-agency operators (e.g., DOT, police, fire, emergency response, border inspections); and
- society as a whole (receives aggregate benefits such as emissions reductions).

The objectives of a market package relate directly to a group or groups of customers, which connects the purpose and intent of the ITS implementation to those being served. When conducting an evaluation, the evaluator should consider the customers and associated objectives that are most important for analysis at that particular juncture. Furthermore, the evaluator should consider establishing specific thresholds by which results can be compared. These thresholds should be defined in the ITS deployment plan and should be based on agency and community goals. Guidance on typical expectations can be found from reviewing anecdotal and quantitative results from other studies (*11*).

Step 4. Identify Appropriate Measures of Effectiveness

The next branch in the evaluation tree is a listing of measures of effectiveness (MOEs) associated with the objective defined above it. There are two basic types of measures identified: output measures and outcome measures.

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

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

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

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

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

- Output measures are typically aggregate facility statistics and, as such, are unable to capture the dynamics of individual traveler responses (as outcome measures typically do).
- Outcome measures are more closely associated with specific transportation goals, such as mobility, accessibility, or safety.
- Output measures are more easily collected/measured because of their aggregate nature, whereas outcome measures require measurement at the individual traveler or company level.

For these reasons, it is necessary to achieve an appropriate balance between output and outcome measures in ITS evaluations (*10*). Both types of measures are included in the MOE portion of the evaluation trees.

Step 5. Seek Guidance on Analytical Approach

The Metropolitan Model Deployment Initiative (MMDI) evaluation strategy of November 1998 (*11*) recommended grouping ITS evaluation studies into six study areas:

- Safety Study,
- Operational Efficiency Study,
- Customer Satisfaction Study,
- Benefit-Cost Study,
- Energy and Emissions Study, and
- Institutional Benefits Study.

These study areas correspond to goals set out in the national ITS program. Table 12 shows the links between the selected market packages, ITS study areas, and the measures of effectiveness associated with each market package. With the exception of the benefit-cost area, analytical commentary on each ITS study area is provided in Appendices B through F of this report. These commentaries will provide guidance to the evaluator on the appropriate methods and techniques to use in evaluating ITS benefits.

Step 6. Select Type of Analysis and Level of Detail

Within a given ITS study area there are two decisions that need to be made by the evaluator: 1) the type of analysis, and 2) the level of detail.

Type of Analysis

Evaluations of ITS impacts can be classified under two basic types of analysis. First, a pre-deployment or prescriptive study, which is designed to predict "with ITS" and "without ITS" scenarios for some length of time into the future. The second is a post-deployment study, which is designed to evaluate "before ITS" and "after ITS" scenarios after ITS components have been deployed. While the measures of effectiveness will be consistent for both analysis types, the approach, technique, or methodology for evaluating benefits may vary. The ITS study areas in Appendices B through F offer guidance for technical approach based on analysis type.

Level of Detail

The evaluator also needs to determine the level of detail and complexity of the evaluation. The research team found significant variance in the complexity of ITS evaluations and concluded that the needed complexity of the evaluation depends upon the: 1) intended end use of evaluation results, 2) data collection cost and/or data availability, 3) scope of the evaluation, and 4) timeframe of the evaluation (*1*). 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.

Figure 9 illustrates the factors to be considered and the influence they have on evaluation complexity.

Table 12. Measures of Effectiveness for Selected Market Packages.

MARKET PACKAGE	STUDY AREAS	MEASURES OF EFFECTIVENESS
Network Surveillance	• Institutional Benefits	• Marginal cost of network surveillance in achieving objectives • Marginal benefit of network surveillance in achieving objectives • Accuracy in monitoring conditions • Time to identify and verify incidents • Cost to collect planning data
Probe Surveillance	• Institutional Benefits	• Marginal cost of probe surveillance in achieving market package objectives • Marginal benefit of probe surveillance in achieving market package objectives • Cost of monitoring conditions • Impacts on toll collection, including cost, vehicle throughput, and average vehicle delay • Cost to collect planning and evaluation data
Surface Street Control	• Safety	• Reduction in overall rate of crashes, crashes involving injury or fatality, crashes involving pedestrians or cyclists
	• Institutional Benefits	• Savings in staff time, equipment costs
	• Operational Efficiency	• Vehicle or person throughput, lane-carrying capacity • Travel time, delay, queue length, bus operating speed • Time between incident and notification, time between notification and response, time between response and arrival • Standard deviation of travel time
	• Customer Satisfaction	• Positive rating
	• Energy and Emissions	• Reduction in emissions • Reduction in fuel consumption
Freeway Control	• Safety	• Crashes or crash rates
	• Operational Efficiency	• Travel time, speed, delay, number of stops, queue length • Standard deviation of travel time • Vehicle or person throughput lane-carrying capacity (v/c)
	• Customer Satisfaction	• Positive rating
	• Energy and Emissions	• Tons of emissions reduced • Gallons saved

Table 12. Measures of Effectiveness for Selected Market Packages (cont.).

MARKET PACKAGE	STUDY AREAS	MEASURES OF EFFECTIVENESS
HOV Lane Management	• Operational Efficiency	• Speed, travel time savings • Standard deviation of travel time • Person throughput, lane-carrying capacity, average vehicle occupancy (AVO)
	• Customer Satisfaction	• Positive rating
	• Institutional Benefits	• Operating costs
	• Energy and Emissions	• Reduction in emissions • Reduction in fuel consumption
Traffic Information Dissemination	• Safety	• Reduction in secondary crashes
	• Operational Efficiency	• Travel time, vehicle hours delay, queue length • Standard deviation of travel time • Lane-carrying capacity, v/c, volume of traffic rerouted
	• Customer Satisfaction	• Positive rating • Opportunity to choose alternative
	• Energy and Emissions	• Reduction in emissions • Reduction in fuel consumption
Regional Traffic Control	• Institutional Benefits	• Marginal cost of communications links and integrated control strategies in achieving combined objectives • Marginal benefit of communications links and integrated control strategies in achieving combined objectives
Incident Management Systems	• Safety	• Reduction in secondary crashes
	• Operational Efficiency	• Time between incident and notification • Time between notification and response • Time between response and arrival at scene • Medical costs • Reduction in travel time, vehicle delay • Standard deviation of travel time • Lane-carrying capacity, v/c
	• Institutional Benefits	• Agency cost savings
	• Energy and Emissions	• Reduction in emissions • Reduction in fuel consumption
Electronic Toll Collection	• Customer Satisfaction	• Positive rating
	• Institutional Benefits	• Vehicle throughput, lane-carrying capacity • Revenue collection costs • Lost revenue • Cost to collect planning data
Standard Railroad Grade Crossing	• Safety	• Number of incidents • Number of crashes • Number of fatalities • Number of injuries • Costs of medical treatment • Costs for property damage
	• Operational Efficiency	• Time between incident and notification • Time between notification and response • Time between response and arrival at scene
	• Institutional Benefits	• Savings in lost time, equipment costs, liability • Vehicle or person throughput, vehicle delay

Table 12. Measures of Effectiveness for Selected Market Packages (cont.).

MARKET PACKAGE	STUDY AREAS	MEASURES OF EFFECTIVENESS
Reversible Lane Management	• Safety	• Reduction in overall rate of crashes, crashes involving injury or fatality • Reduction in wrong-way incidents
	• Operational Efficiency	• Time between detected change in demand and field response • Travel time, delay, queue length • Vehicle or person throughput, lane-carrying capacity
	• Institutional Benefits	• Savings in staff time, equipment costs • Vehicle operation and maintenance costs
	• Energy and Emissions	• Reduction in emissions • Reduction in fuel consumption
Broadcast Traveler Information	• Operational Efficiency	• Travel time savings, queue length, congestions and incident-related delay, veh-hrs of delay
		• Standard deviation of travel time
		• VMT, lane-carrying capacity, v/c, traffic volumes
Electronic Clearance	• Customer Satisfaction	• Positive/negative rating
	• Operational Efficiency	• Travel time through checkpoint • Commercial vehicle throughput at checkpoints
	• Institutional Benefits	• Commercial vehicle inspection costs • Number of citations issued
CV Administrative Processes	• Institutional Benefits (Agency)	• Application cost • Processing cost • Fee collection • Number of licenses issued • Number of credential or license taxes
	• Institutional Benefits (Other Government Offices)	• Number of vehicle information records from other agencies
	• Institutional Benefits (Carriers)	• Administrative cost per vehicle
International Border Electronic Clearance	• Safety	• Crash rate by border crossing CV
	• Operational Efficiency	• Average CV border crossing delay • Standard deviation of crossing time • Number of CV per open booth, per day
	• Institutional Benefits	• Cost of staff per inspected CV
	• Energy and Emissions	• Reduction in emissions • Reduction in fuel consumption
Weigh- in-Motion	• Operational Efficiency	• Number of stops • Travel time total
	• Institutional Benefits	• Number of inspected vehicles • Cost of inspections
Roadside CVO Safety	• Safety	• Reduction in crashes
	• Operational Efficiency	• Delay at inspection facility • Number of inspected CVs per station • Number of inspected CVs with missing/incomplete documents
Emergency Response	• Institutional Benefits	• Marginal cost of communications systems in achieving market package objectives • Marginal benefit of communications systems in achieving market package objectives

Table 12. Measures of Effectiveness for Selected Market Packages (cont.).

<table>
<tr><th>MARKET PACKAGE</th><th>STUDY AREAS</th><th>MEASURES OF EFFECTIVENESS</th></tr>
<tr><td rowspan="3">Emergency Routing</td><td>• Safety</td><td>• Reduction in secondary crashes</td></tr>
<tr><td>• Operational Efficiency</td><td>• Reduction in travel time delay
• Time between notification and arrival
• Time between departure from scene and arrival at care facility
• Savings in medical costs
• Travel time, vehicle hours delay, queue length
• Standard deviation of travel time
• Lane-carrying capacity, v/c, volumes</td></tr>
<tr><td>• Institutional Benefits</td><td>• Administrative and regulatory cost savings
• Manpower savings, vehicle maintenance and depreciation costs</td></tr>
<tr><td>Road Weather Data Collection</td><td>• Institutional Benefits</td><td>• Marginal cost of RWDC in achieving weather info processing and distribution
• Marginal benefit of RWDC in achieving weather info processing and distribution
• Accuracy in monitoring weather conditions
• Time to identify and verify weather-related problems
• Cost to collect weather data</td></tr>
<tr><td rowspan="3">Weather Information Processing and Distribution</td><td>• Safety</td><td>• Number of incidents
• Number of crashes
• Number of fatalities
• Number of injuries
• Costs for medical treatment</td></tr>
<tr><td>• Customer Satisfaction</td><td>• Positive rating</td></tr>
<tr><td>• Operational Efficiency</td><td>• Standard deviation of travel time
• Operating cost savings
• Administrative and regulatory cost savings
• Manpower savings
• Savings in vehicle maintenance and depreciation</td></tr>
<tr><td rowspan="3">Work Zone Management</td><td>• Operational Efficiency</td><td>• Travel time, vehicle hours delay, queue length
• Standard deviation of travel time
• Lane-carrying capacity, v/c, volumes</td></tr>
<tr><td>• Customer Satisfaction</td><td>• Positive rating
• Opportunity to choose alternative</td></tr>
<tr><td>• Energy and Emissions</td><td>• Reduction in emissions
• Reduction in fuel consumption</td></tr>
</table>

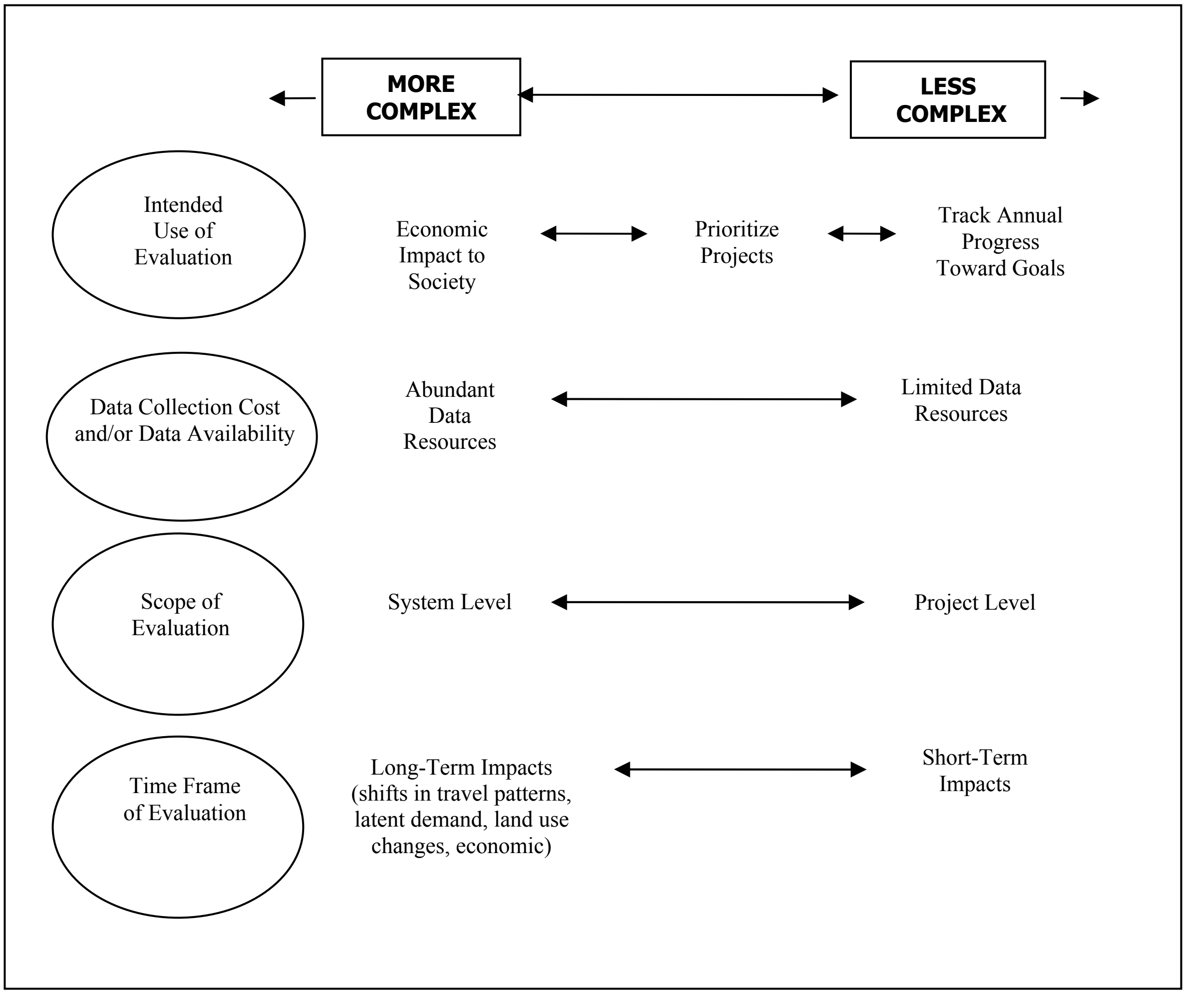


Figure 9. Evaluation Complexity.

Evaluation Cost

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

Evaluation Time Frame

ITS evaluation plans should recognize the time frame of occurrence for benefits and impacts of ITS (*2*). Some of the impacts, such as increased throughput or decreased travel time, may be seen almost immediately. Other impacts, such as changes in land use or economic productivity, may not be evident for many years. As an example, evaluation plans might use these or similar time frame categories:

- **Short term** – benefits/impacts occurring within two years after implementation;
- **Medium term** – benefits/impacts occurring between two and five years after implementation; and
- **Long term** – benefits/impacts occurring five years or more after implementation.

The analytical commentary provided in the ITS study areas found in Appendices B through F of this report offer guidance in conducting evaluations for different levels of complexity.

Step 7. Identify Data Needs and Analysis Technique

The ITS study areas found in Appendices B through F provide information on the type of data needed for a given analysis technique. Data requirements will differ depending on the ITS evaluation method:

- simulation modeling or spreadsheet modeling, which can be utilized for both pre-deployment and post-deployment evaluations; and
- field observations of MOEs, which are utilized in a post-deployment evaluation but require pre-deployment data for comparison.

Simulation Modeling Evaluation Method

Simulation modeling has several purposes, such as estimating impacts of ITS deployments before the decision to deploy is made and estimating impacts of individual components of an ITS deployment, as well as estimating the impacts of the integration of multiple ITS components. While these attributes are positive, the drawbacks include the amount of data collection required and the degree to which the model's algorithms replicate real-world activities such as various traffic flow and travel demand characteristics. Table 13 and Table 14 summarize the data requirement potential under the simulation modeling evaluation method.

Data requirements will vary depending on the study type:

- operational efficiency,
- energy and emissions,
- safety,
- customer satisfaction, or
- institutional benefits.

Data requirements for simulation modeling also will vary depending on the need to evaluate the impacts of ITS under various supply (effective capacity) and demand scenarios such as:

- incident versus non-incident conditions,
- good weather versus bad weather conditions,
- special events,
- seasonal demand levels,
- peak versus off-peak periods, and
- weekday versus weekend.

Some of the data required as inputs into a simulation modeling study, such as incident and crash impacts on effective capacity reduction, can be found in the transportation literature. Data of this type, some of which have been presented in this report, could be used in lieu of collecting local data.

Spreadsheet modeling uses computational tools and techniques in combination with historical data to estimate impacts of ITS in either pre-deployment or post-deployment scenarios. While spreadsheet modeling may not produce the same quality of result as more comprehensive simulation, it will often be sufficient for the decisions at hand. The ITS Deployment Analysis System described in Chapter 3 is the most comprehensive spreadsheet model currently available. One of the advantages of IDAS is the relatively low time requirement for the modest data entry. The product uses a high number of default assumptions that may affect accuracy and results, but allows user override for improved analysis.

Table 13. Simulation Model Evaluation Potential Data Requirements Concerning Operational Characteristics of Transportation Infrastructure.

With ITS and Without ITS
Volumes
Speeds
Queues
Signal Timing Parameters
Historical Incident Characteristics Type Reduction in effective capacity Time to detect Time to respond Time to clear
Historical Crash Characteristics Number Rate Severity
Effective Capacity
Volume-to-Capacity Ratio
Lane Density
Lane Occupancy
Lane Changing Number Intensity "Smoothness"
Headways
Lane Utilization
Lane Restrictions
Transaction Time at Toll Booths By Vehicle Category and Transaction Type
Freeway Access
Lane Speed Differentials

Table 14. Simulation Model Evaluation Potential Data Requirements Concerning Travel Demand Characteristics.

With ITS and Without ITS
Trip Generation Trip Demand
Temporal Diversion Potential with Access to Various Types of Pre-Trip Traffic Information (local or national surveys, field observations, transportation literature)
Trip Distribution Origin-to-Destination Data
Mode Choice Mode Change Potential with Access to Various Types of Pre-Trip Traffic Information (local or national surveys, field observations, transportation literature)
Route Choice Route Diversion Potential with Access to Various Types of Pre-trip and En Route Traffic Information (local or national surveys, field observations, transportation literature)

Field Observation Evaluation Method

In the field observation method, MOEs are observed in the field before and after ITS deployment rather than attempting to predict them through simulation modeling. Thus, the data requirements are a function of the MOEs discussed in Appendix B of this report, such as travel delay, travel time reliability, crashes, emissions, etc.

While field observations of MOEs have the advantage of basing conclusions on actual empirical data (rather than simulation model outputs), the field observation method is typically conducted after ITS deployment and, therefore, precludes its usefulness in the decision to deploy beforehand. The field observation method still requires proper analytical procedures when comparing the before and after ITS deployment scenarios in order to minimize threats to the validity of the analysis. Regardless of the study area (operational efficiency, safety, etc.), data analysis issues, such as controlling for other non-ITS explanatory factors, need to be taken into account. These considerations can, in turn, lead to large data collection requirements.

Core Data Requirements

Given the large amount of data that is potentially needed for either simulation modeling or field evaluation of ITS deployments, in this section we present a list of what we consider to be core field data requirements that TxDOT should consider.

The locations for data collection include subsections of freeway mainline, ramps, managed lanes, toll facilities, and inspection facilities, as well as frontage roads and other surface streets and railroad crossings.

The conditions under which data should be collected include:

- incident versus non-incident conditions,
- good weather versus bad weather conditions,
- work zones versus non-work zones,
- special events,
- seasonal demand levels,
- peak versus off-peak periods, and
- weekday versus weekend.

The collection of core data is recommended.

- traffic volumes by vehicle type;
- travel times or speeds;
- speed limits;
- vehicle occupancy;
- queue lengths;
- incidents by type (crash or disablement), time to detect, time to verify and respond, time to clear, lateral location (shoulder or lane blockage), and severity (fatality, injury, or property damage only);
- customer satisfaction data; and
- costs to collect data (initial capital, operations and maintenance, labor, on-the-job injuries).

Steps 8 and 9. Collect Data, Perform Analysis, and Evaluate Results

Once the data sources have been identified, the evaluator can proceed with collecting the data, performing the analysis, and evaluating the results. Important in the evaluation of results is the ability to determine what constitutes "success." This capability requires the establishment of threshold values for MOEs beforehand. For instance, a measure of effectiveness that is actually quantifiable would be, "a 10 percent reduction in vehicle hours of delay." If not established in the ITS deployment plan, then the agency should establish measurable values prior to deployment and before initiation of the evaluation process.

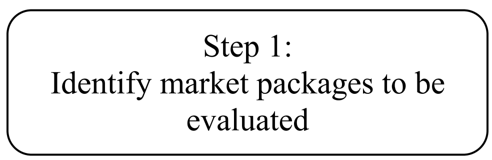
EXAMPLE EVALUATIONS

To illustrate the application of the evaluation trees, two examples are presented in this section. The first example is that of a non-metro application – in this case, installation of weather monitoring devices and dynamic message signs to alert drivers to weather conditions and possible road closures. The second example is more common – the expansion of an existing freeway control system to cover a greater portion of a metro area. Both examples follow the recommended evaluation process and use the evaluation trees in Appendix A.

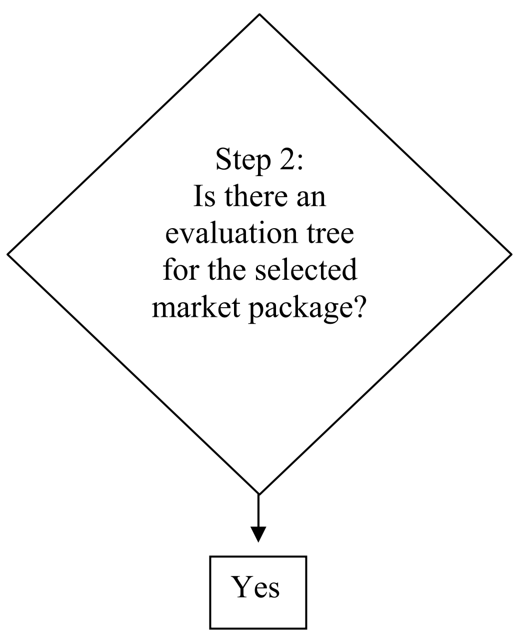
Example: Evaluation of Weather Warning System – Non-Metro ITS Project

Situation: A non-metro district of the Texas Department of Transportation (TxDOT) has identified an opportunity to improve traveler convenience and safety by assisting them in avoiding road closures or choke points due to weather, construction, and incidents. Because a bypass is available, TxDOT is able to reroute hundreds of vehicles to significantly reduce their delay and inconvenience.

This example will use the weather information market packages to illustrate the evaluation process, following the flowchart in Figure 2, repeated in parts below.



Two packages are relevant to this effort. Although Weather Information Processing and Distribution (MC 04) is the principal package, a detection mechanism, such as Road Weather Data Collection (MC 03) is also required. In this case, the area subject to weather incidents is under network surveillance, so no additional detection equipment is required.



From Appendix A, we retrieve the evaluation tree for Weather Information Processing and Distribution, shown in Figure 10.

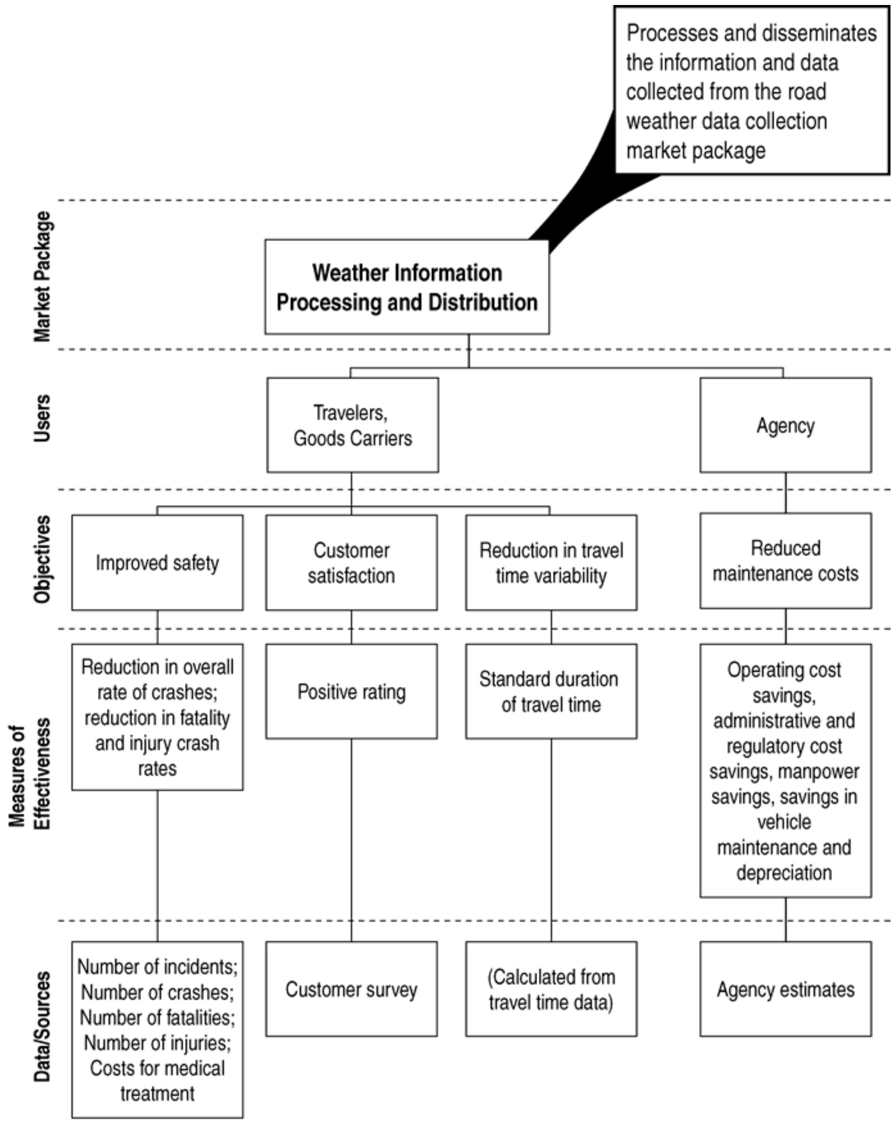


Figure 10. Weather Information Processing and Distribution.

Step 3: Identify customer group(s) and objectives of interest from evaluation tree

As shown there are a number of potential benefits that accrue from this market package. The District has identified reducing travel time as the primary objective of the deployment. (It should be noted that multiple objectives can be pursued and the results added; for this example, only one objective and measure of effectiveness will be illustrated.)

Step 4:
Determine appropriate measures of effectiveness (MOEs) to use based on customer group and objectives

This particular objective is self-describing for the appropriate measure of effectiveness – reduction in travel time. Travel time reduction relates to the improvement in travel time from Point A (upstream of the ITS system) to Point B (beyond the blockage) with the deployed market package compared to a base case without the market package. In this situation, the appropriate differential will be one of two possibilities. If travelers will be expected to remain on the original route until the weather blockage is cleared, then that duration will be the base condition. If they would typically turn around to another route (in the absence of the advance warning), then the total time to reach Point B is the base case.

Step 5:
Refer to designated "ITS Study Area" for guidance on analytical approach and data requirements

For technical guidance, the analyst could refer to Appendix B, which has notes and suggestions for analysis of operational measures of effectiveness.

Prescriptive, or Pre-deployment ← Step 6: Select type of analysis and level of detail → Post-deployment, or "Before versus After" study

This step is usually self-evident. If the District has already deployed the ITS package, then the post-deployment approach would be appropriate. Appendix B gives guidance on Before and After studies. However, the level of detail is very important. If the purpose is to confirm the general benefits derived or demonstrate for the community the value of deployed technology, then estimates of travel time saved and number of travelers and commercial vehicles affected would be sufficient.

If the purpose is to compare the relative merits of two prospective ITS projects, then the analyst will want to use similar levels of detail and precision on both projects.

Step 7:
Identify data needed and analysis tool/technique

Once again, the application of this step is straightforward, though users would always be wise to apply some simple logic to their approach: Do the measures I am using make sense? Are the results reasonable? Is my level of precision appropriate (caution not to make highly precise calculations using estimated values)?

Step 8:
Collect data and perform analysis

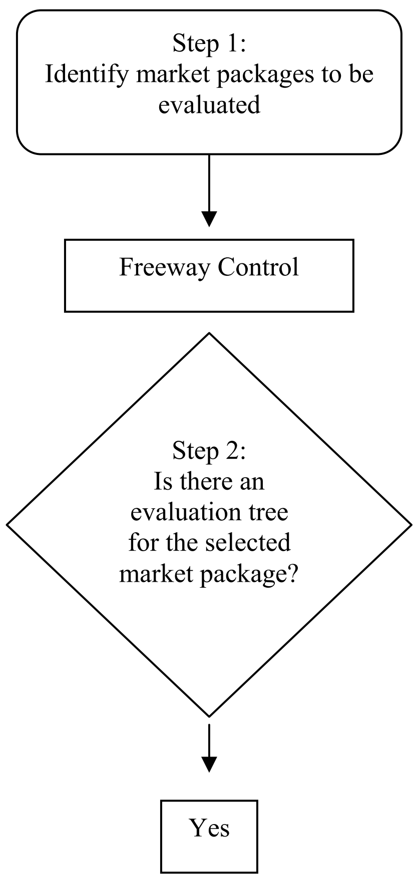
In this case, two or three pieces of data are needed. The first is the travel time differential measured or calculated. The magnitude of the impact will be a function of the number of users affected. If trucks represent a significant portion of the traffic stream, they should be recorded separately. At this point, it is possible to multiply the travel time savings by the number of passenger cars and trucks to estimate total savings. If desired, multiplying these savings by the road user cost is applicable. TxDOT's Traffic Operations Division or Construction Division will be able to provide current estimates. The 1998 values were $14.30 and $20.50, for cars and trucks, respectively.

Step 9:
Compare results to objectives

This last step is very important. ITS projects are deployed to accomplish a public purpose, which should be captured in the objectives. This step compares the data from Step 8 with the original objectives. If the objectives have been met or exceeded, the message should get out to the beneficiaries. If the objectives have not been met, then the implementing group should examine what reasons may explain that and whether there are adjustments to be made in the deployment to improve performance.

Example: Expansion of a Metropolitan Freeway Control System

Situation: A metropolitan district of TxDOT has successfully deployed a freeway control system to a portion of the freeway network in the city and is considering expanding the ITS network further. District staff believe that two principal objectives justify the potential expansion: improved safety and improved customer satisfaction. The evaluation based on the evaluation process in Figure 2 follows:



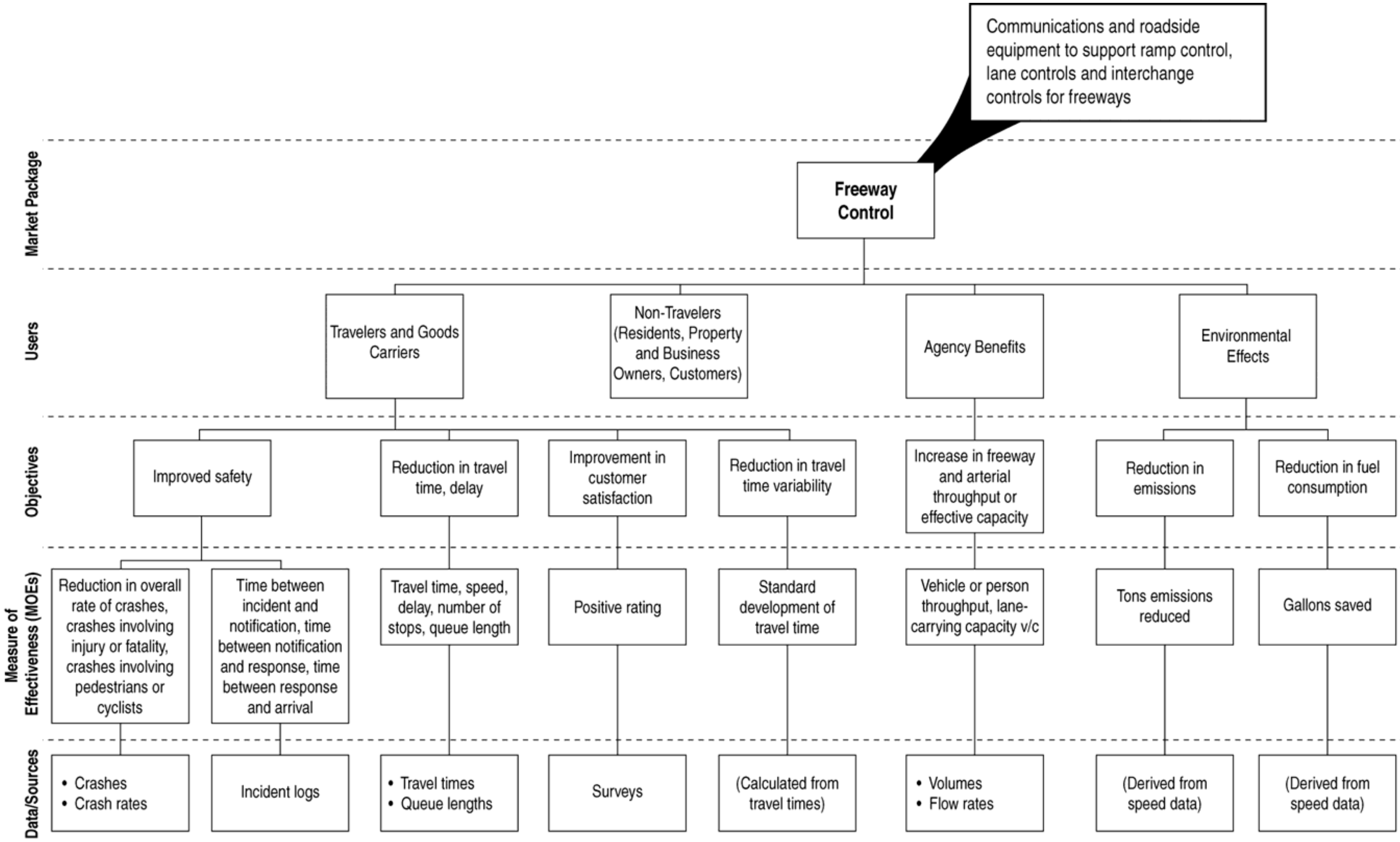


Figure 11. Freeway Control.

Step 3:
Identify customer group(s) and objectives of interest from evaluation tree

TxDOT staff had identified both improved safety and improved customer satisfaction as the primary objectives, so the evaluation follows both tracks.

Step 4:
Determine appropriate measures of effectiveness (MOEs) to use based on customer group and objectives

Based on the characteristics of this portion of the freeway network, the staff concluded that secondary crashes would be the most important safety measure of effectiveness for this deployment. Similarly, the level of positive rating in customer satisfaction would be the other preferred MOE.

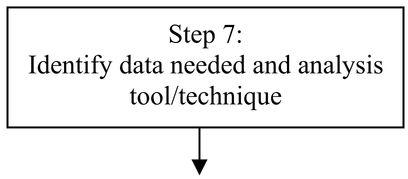
Step 5:
Refer to designated "ITS Study Area" for guidance on analytical approach and data requirements

Appendix C provides additional information on Safety MOEs and Appendix D discusses various approaches to measuring customer satisfaction. In deciding on an appropriate approach, the evaluator should consider the level of effort and data requirements. If possible, choose an approach that minimizes additional data collection, beyond that normally available.

Step 6:
Select type of analysis and level of detail

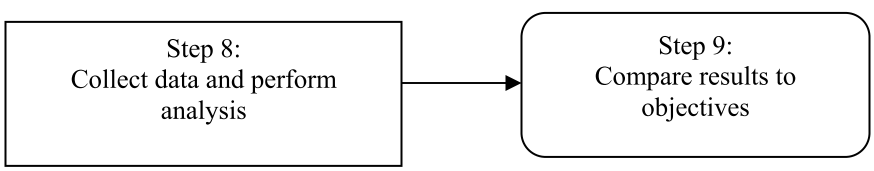
Prescriptive, or Pre-deployment

Unlike the previous example, this one has been described as a prospective look at the potential benefits of expanding the freeway control network. Therefore, the type of analysis and level of detail should be commensurate with the intended purpose. If the district plans to compare the cost of deployment with the anticipated benefits (converted to monetary units), then the level of precision in the benefits estimation should match the precision of the cost estimate, as closely as practical.



In this case, the district's previous experience with the freeway control market package provides an excellent comparative base. Before and after secondary crash data from the existing network under freeway control should be an excellent source for base data. Applying that ratio to the historic data for the network segments under review will provide some indication of the magnitude of the safety benefits.

With respect to customer satisfaction, telephone surveys, mail-out surveys, or focus groups of potential customers will likely be required. It is important in this phase to assure that the respondents are selected to assure no biases in their responses.



Completion of the evaluation process for the freeway control expansion is similar to that of the weather application. Safety data will describe the traveler benefits, and customer satisfaction will describe community desire.

Closure

Of primary importance in applying this evaluation methodology is following the methodology. Ultimately, that will assure that the evaluator can compare the result with the original objectives, an outcome frequently lacking in ITS evaluations. The evaluator should strive for objectives that fit the situation better than the generic objectives presented in the evaluation trees. Likewise, better measures of effectiveness will improve the quality of the outcome. Over time, TxDOT will develop sufficient expertise to update the evaluation process to reflect Texas-specific results.

CHAPTER 5: FINDINGS AND RECOMMENDATIONS

There is ample, even overwhelming anecdotal evidence that many ITS deployments have been highly beneficial. The magnitude of benefits experienced has varied substantially among market packages and among individual deployments within a market package. A "market package" is an industry term describing those technologies that are likely to be deployed together as a "package." This terminology differs from the original "user services," because it was observed that the deployment approaches do not directly match user services. A matrix illustrating how market packages are used to deliver user services is shown in Table 1.

This chapter summarizes the benefits of ITS that have been documented and reported to date. The physical and operational characteristics of ITS deployments have been as varied as the sites, so the many data points are too scattered to allow the development of predictive equations or rules of thumb. Ranges of potential benefits are much more appropriate and verifiable, so they are included in the discussion.

Ultimately, it will be highly desirable for transportation professionals to have a guide to ITS project evaluation that would produce results similar to those provided by the *Highway Capacity Manual* (HCM) (*12*). The HCM allows the user to input situational conditions and examine alternative approaches to capacity improvements. At present such a guide does not exist for ITS primarily because the experience and research to create such a guide has not evolved. The current HCM reflects more than 50 years of experience, research, and documentation and is much more sophisticated than the HCM of the 1970s. Experience with ITS, however, is barely a decade old. Furthermore, the documentation of ITS projects has been inconsistent at best, resulting in apples-to-oranges comparisons in many, if not most, cases. The evaluation framework presented in this report will go a long way to correct the inconsistency and incompatibility of ITS evaluations, ultimately allowing the accumulation of sufficient experience to develop supplements to the HCM that address ITS contributions.

It is very important to point out that positive results stem from prudent deployments. The results illustrated in this chapter are from successful and prudent deployments. Positive results from a ramp-metering project do not mean that all freeways need ramp metering any more than positive results from signal timing mean all intersections need signals.

Furthermore, the results and experience with ITS deployments are changing too rapidly to attempt to capture meaningful benefit estimates in a static medium such as a research report. The reader is strongly urged to use the resources provided by the U.S. Department of Transportation (USDOT) through the ITS Joint Program Office (JPO). The websites listed below are excellent and are valid links as of the publishing date of this report. They will provide more comprehensive relevant and up-to-date information than can be captured here (*12*, *13*).

http://www.its.dot.gov

http://tti.tamu.edu/austin/its

FINDINGS IN GENERAL

All economic measures of merit (e.g., benefit-cost ratio, cost-effectiveness) have shown that well-chosen deployments rank very high among transportation projects. The key to "well-chosen" appears to be consistent with the normal project selection process at TxDOT – goal-oriented, clear objectives, and realistic expectations.

A goal-oriented, multi-step process to develop an evaluation framework and plan helps assure that agencies set reasonable expectations for deployments and accurately measure progress toward defined objectives. The guidelines included are based on the recommended evaluation framework, as described in Chapter 3.

The guidelines presented herein provide a well-structured process for evaluating ITS market package deployments, assuring thoroughness and consistency. These guidelines provide a step-by-step method for estimating potential impacts of prospective deployments, as well as for evaluating existing deployments. Recommendations for data collection are included for each type of evaluation.

Experience with ITS deployments and estimates of benefits that can be expected are constantly changing. Websites identified in the body of the report and in the appendices are the best sources for current estimates and experience.

Customer satisfaction with ITS projects is typically high. However, customer satisfaction tends not to be well recognized or measured by deploying agencies.

Lessons learned from ITS deployments have been generally well documented, and those products and services that were not successful have fairly quickly disappeared.

There are valuable tools available to assist in the assessment of prospective ITS deployments. The SCRITS and IDAS computer-based tools, as described in Chapter 4, make use of current databases to estimate potential benefits. The IDAS tool allows the analyst to include the interactive benefits of the deployment of multiple market packages.

Evaluations

Evaluations of ITS projects have not been consistent. Many deployments have not been objectively evaluated at all. Many others have been evaluated with specific purposes in mind and, as a result, tended to use locally defined measures of effectiveness and estimation techniques.

The level of deployment of ITS, combined with the limited transferability of evaluation findings among projects, precludes development of prediction equations at this time. As multiple evaluations of individual market packages are performed and documented under a wide range of traffic and relevant local conditions, the ability to make reliable and defensible predictions will improve. One of the principal benefits of rigorous pursuit of the guidelines recommended herein is the meaningful contribution to the body of knowledge about ITS projects.

Traditional traffic engineering measures of effectiveness have some limitations in gauging the value of ITS projects. In many cases ITS projects produce outcomes that are individual in nature, while most traffic engineering measures are measures of aggregate output, rather than outcome.

System Considerations

Among the most important but least appreciated elements of ITS deployment are the backbone communications and operating systems. While they produce little if any benefit of their own, they are essential to the provision of all ITS services. These systems are analogous to right-of-way in traditional highway systems – it does not directly serve mobility, but is intrinsic to the provision of mobility.

Deployments that are part of an overall system of improvements may produce more benefits than isolated individual deployments. This difference is because each deployment requires a supporting system of communications and operations. Subsequent deployments can often capitalize on the availability of these supporting systems.

Similar logic applies to the value of continuity in a system. Extension of ITS services to increasing parts of the network not only provides broader service at decreasing marginal cost, but also allows the traveling public to become adapted to and reliant upon the services, further increasing the cost-effectiveness.

Because there is continual change in technology, the eventual obsolescence of ITS projects must be recognized from the outset. This obsolescence can be viewed as opportunities rather than obstacles, allowing refinements and adjustments in the type and scope of ITS services to be tailored to public demands. Obsolete supporting systems can become the limiting element if they are not upgraded to meet changing requirements.

Inadequate investment in maintenance and operations can dramatically affect the level of benefits derived from an ITS deployment. Sufficient and trained operations staff and adequate equipment maintenance are as much a part of providing transportation services as pavement maintenance.

SUMMARY OF BENEFITS

Benefits to Travelers

ITS deployments have a substantial impact on safety that is not achievable by other means. Figure 12, 13, and 14 illustrate the range of benefits achieved among deployed ITS projects on freeways, arterials, and toll roads respectively (*5*). Crash reductions of 5 to 50 percent resulted from ramp-metering deployments in Seattle, Denver, Portland, Detroit, and Minneapolis. ITS incident management deployments have reduced total crashes by 35 percent in San Antonio and are projected to impact typical metropolitan areas by 11 to 15 percent nationwide due to reduced incident detection and response times. Deployments at railroad-highway grade crossings reduced high-risk violations by 26 to 92 percent. Traffic signal coordination reduced vehicle stops (that potentially lead to crashes) by 28 to 43 percent.

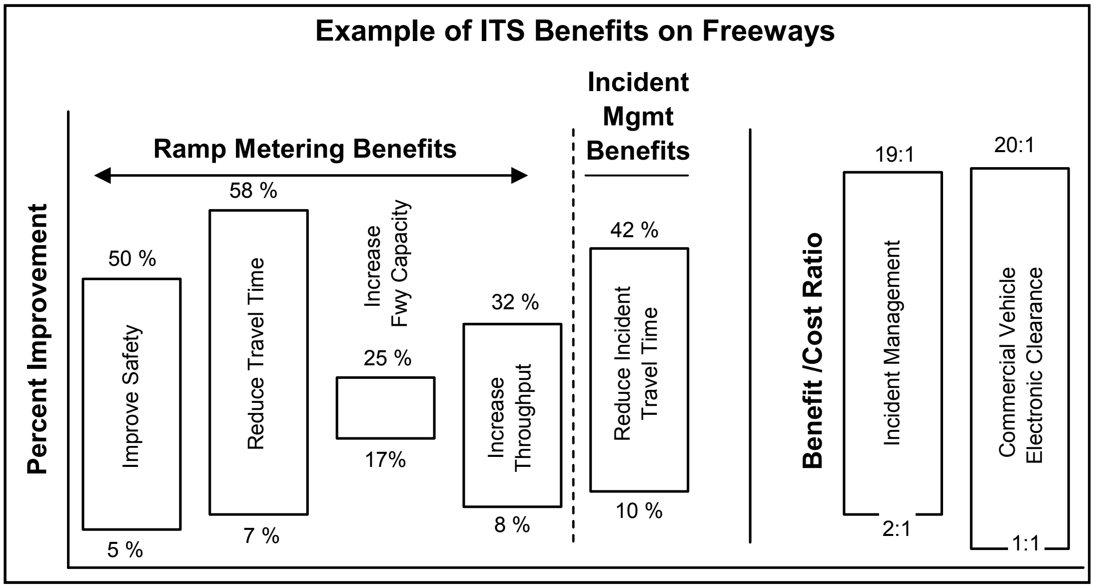


Figure 12. Typical Ranges of Benefits Measured or Estimated from Freeway ITS Deployments Nationwide (*5*).

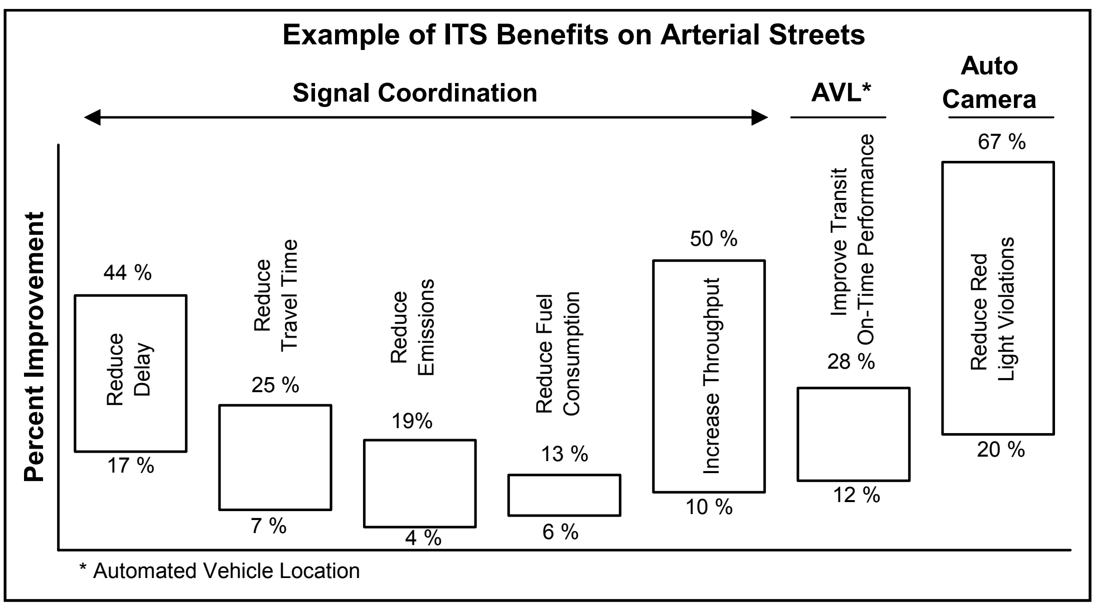


Figure 13. Typical Ranges of Benefits Measured or Estimated from Arterial Street ITS Deployments Nationwide (5).

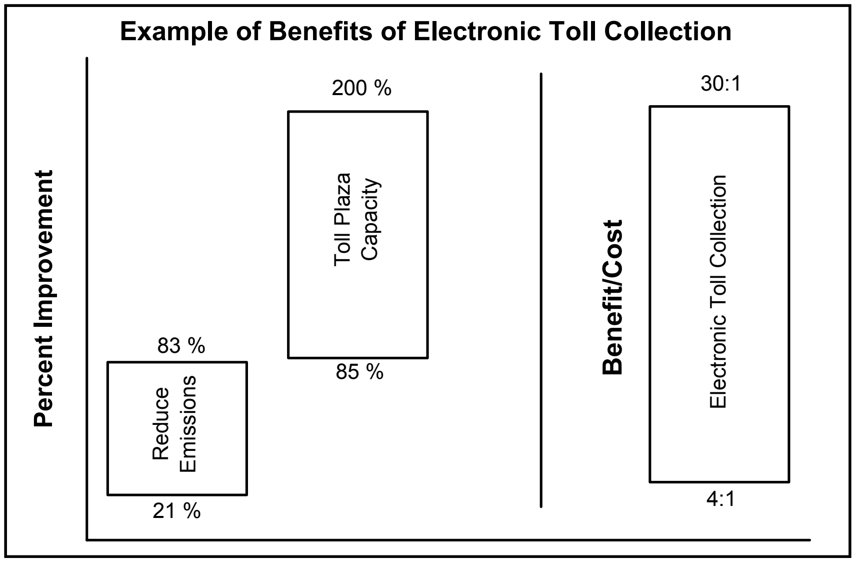


Figure 14.Typical Ranges of Benefits Measured or Estimated from Toll Road ITS Deployments Nationwide (*5*).

Delays on freeways and arterial streets can be significantly reduced through deployment of selected ITS projects. Traffic signal coordination reduced travel times by 8 to 25 percent nationally and reduced delays on arterial streets by 15 to 50 percent. Incident management systems nationwide have typically reduced incident-related delay 50 to 60 percent as a result of rapid detection of and response to crashes and stalls. Ramp-metering systems reduce travel time by 10 to 27 percent. On-time performance of bus systems with automated vehicle location systems has improved 12 to 28 percent. Queues at toll plazas have decreased dramatically with the deployment of electronic toll collection (ETC).

The traveling public strongly supports better information and more reliable travel times made possible by ITS deployments, expressing very high levels of favorable response to a wide range of deployments. Incident locations, travel times, rerouting information, weather warnings, and Amber Alerts are possible because of the ITS infrastructure, roadside signs, and highway advisory radios. In Orlando, 58 to 67 percent of users believe roadside dynamic message signs (DMS) are accurate and timely. In Indiana, more than 75 percent of participants were favorable to DMS installations. Automated warning signs have even higher levels of approval – 69 to 85 percent. Ramp metering was favored by 80 percent of survey respondents in Minneapolis – *after* ramp metering had been discontinued for a lengthy period. Internet access has radically changed customer expectations, especially regarding information; meaningful real-time information is contingent upon a good ITS network. Websites with local traffic information have seen dramatic increases in usage, especially as they expand the nature of information available and provide timely and reliable information.

Key ITS deployments can provide critical services to assure truck safety and efficiency. A midwest project increased the identification and removal of unsafe drivers and vehicles by 50 percent. Colorado has experienced a 13 percent drop in truck crashes resulting from a downhill speed sensor/monitor that reports excessive speed. Electronic credentials projects have reduced processing time from six weeks or more to less than an hour. Numerous truck rollover projects have been implemented, most commonly at freeway-to-freeway connector ramps. Roadside electronic screening and weigh-in-motion are central to Texas' long-term strategy for minimizing weigh station staffing requirements and maximizing safety screening.

Benefits to Society

Numerous ITS projects have saved fuel consumption well in excess of the cost of the deployment. Signal coordination reduced fuel consumption by 5 to 15 percent over a range of traffic and local conditions. Fuel savings resulting from ramp metering ranged from 135,000 gallons in Portland to 5.5 million gallons annually in Minneapolis/St. Paul. Fuel savings of 2600 gallons *per incident* are an estimated impact for the San Antonio TransGuide center. Based on the study of 297 areas, minimum savings of 6 percent are estimated for deployment of the basic metropolitan ITS infrastructure.

A wide range of ITS deployments has had measurable impacts on emissions. Reductions of hydrocarbons (HCs) and carbon monoxide (CO) ranged from 4 to 19 percent for traffic signal coordination projects, with most projects producing double-digit reductions. Estimates of the impact of the traffic management center in Detroit are annual reductions of: 1400 tons of HC, 122,000 tons of CO, and 1200 tons of NO_{x}. The metropolitan ITS infrastructure is conservatively estimated to save a base of 6 percent in corridor emissions.

Benefits to Transportation Agencies

Increased throughput on freeway and tollway lanes substantially improves the effectiveness of the facility. Such improvements may postpone the need to widen freeways, or at least lessen impacts until capacity improvements can be implemented. Nationwide the improvements range from 8 percent to 22 percent, effecting a temporary increase in capacity simply by making more efficient use of existing capacity.

Additional agency benefits include:

- Because technologies can significantly speed up manual tasks, the available transportation agency staffs can be much more effective and have a much greater reach and impact.
- Because ITS technologies can be deployed and operated remotely, traveler information and warnings, roadway safety, and traffic operations can be monitored and adjusted and responses sent in ways never before possible.
- A wide range of ITS deployment shows substantial savings in transportation agency operations and traveling public time and expense.
- Because most ITS deployments either directly or indirectly involve multiple agencies, ITS has an integrating effect that is not readily quantifiable but is evident during major events, such as disasters, both natural and manmade.

ITS projects are a complement to traditional infrastructure projects. As has been shown throughout this report, properly selected and deployed ITS projects increase the efficiency and effectiveness of infrastructure projects, at levels well beyond the cost of the ITS components.

REOMMENDATIONS

The authors have the following recommendations:

- When an evaluation of a prospective ITS project is warranted, it should be evaluated using the guidelines contained in Chapter 4.

- For existing projects that warrant a post-deployment evaluation:
    - use the guidelines to identify appropriate measures of effectiveness,
    - continue or establish data collection plans to support the measures of effectiveness, and
    - analyze the data and make adjustments to deployments and operations to maximize effectiveness.

- That TxDOT establish and maintain an ongoing system of documentation of the results of these evaluations as a means of contributing to TxDOT's body of knowledge on the benefits of ITS, as well as the larger body of knowledge maintained by the ITS Joint Program Office.

- That TxDOT recognize the requirement to continually update, modernize, and reinvest in ITS projects.

- That TxDOT recognize the necessity to provide adequate ongoing funding for the maintenance and operations of ITS deployments.

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APPENDICES

APPENDIX A: MARKET PACKAGE EVALUATION METHODOLOGY

MARKET PACKAGE EVALUATION TREES

Appendix A presents the ITS evaluation trees for 26 selected market packages. Included with each is: 1) a market package description, 2) analytical notes pertinent to the particular package to be used in conjunction with the ITS study area guidance in Appendices B through F, and 3) the market package evaluation tree.

ATMS01 – Network Surveillance

Description

This package provides the basic sensory elements of traffic management. These include surveillance equipment, traffic detectors, wireless communication, and supporting field equipment. The data generated by this market package allow for monitoring of traffic and road conditions, identification or verification of traffic incidents, detection of faults in indicator operations, and collection of census data for long-range planning. (See Figure A-1.)

Analytical Commentary

Benefits of this market package accrue primarily to the agency. Network surveillance supports other market packages (e.g., surface street control, freeway control, HOV lane management, regional traffic control, incident management, etc.), and, on its own, improves the reliability of monitoring, detecting, or collecting data. The evaluator should refer to the institutional benefits study area in Appendix F for guidance.

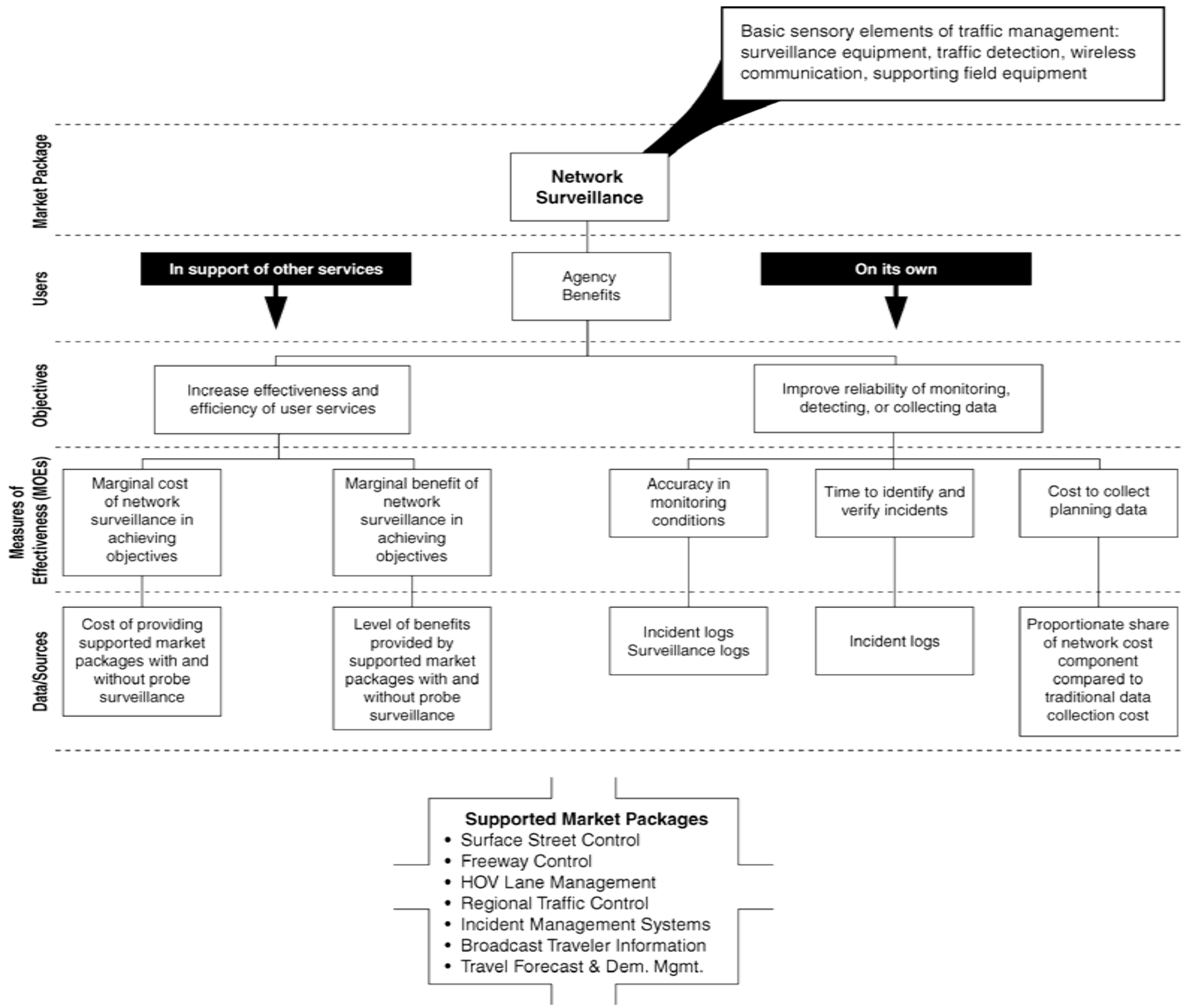

Figure A-1. ATMSO1 – Network Surveillance.

ATMS02 – Probe Surveillance

Description

This is a potentially cost-saving alternative to network surveillance. This market package, like network surveillance, is a core function providing information to other traffic management and traveler information services. There are two general implementation paths for this package: 1) wide area wireless communications between vehicle and information service provider (ISP) to communicate vehicle location and status; and 2) short-range communications between the vehicle and the roadside to provide information to the traffic management center. (See Figure A-2.)

Analytical Commentary

Benefits of this market package accrue primarily to the agency. Probe surveillance supports other market packages (e.g., incident management, electronic toll collection, broadcast traveler information, etc.), and, on its own, improves the reliability of monitoring, detecting, or collecting data. The evaluator should refer to the institutional benefits study area (Appendix F) for guidance.

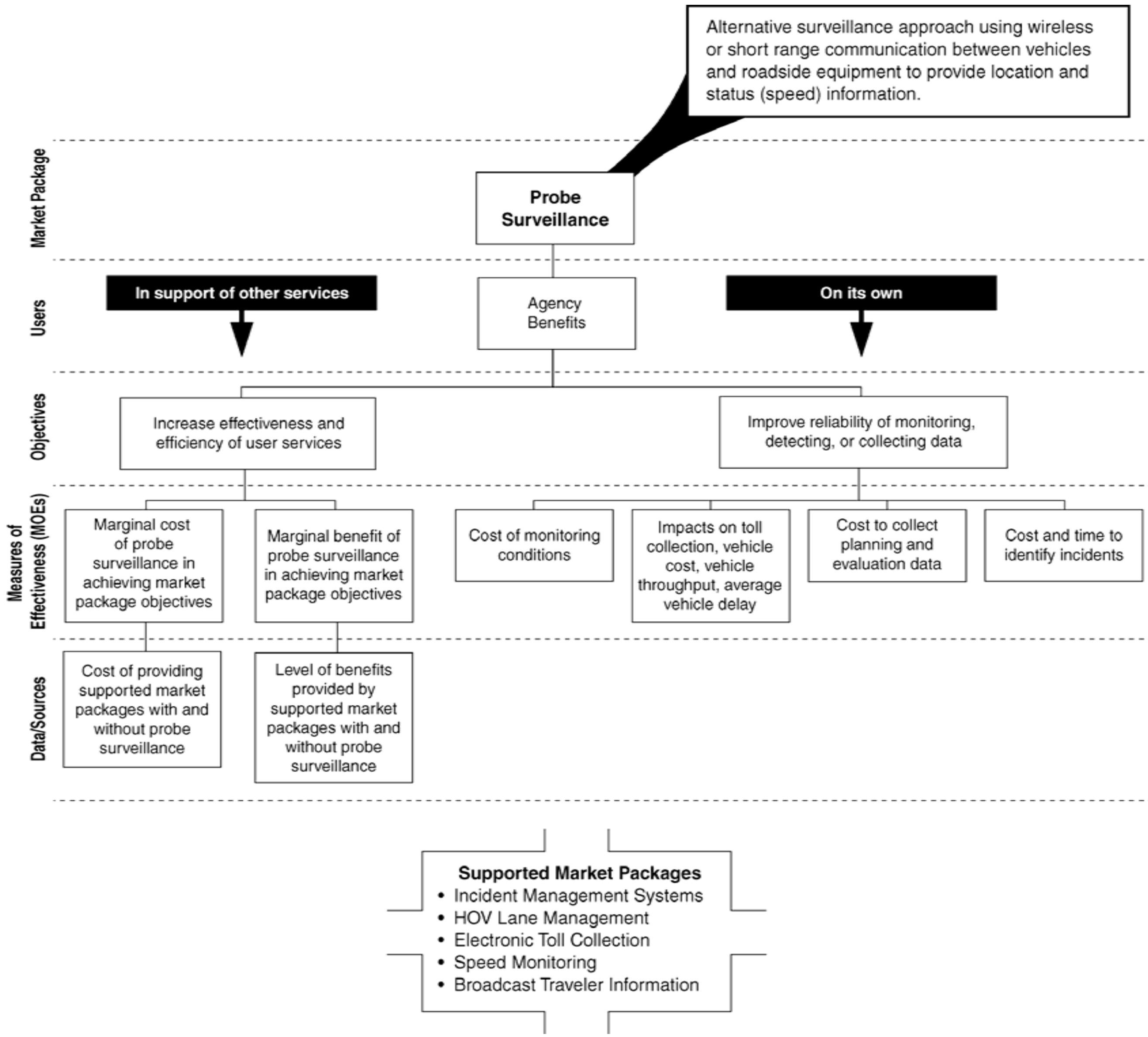

Figure A-2. ATMS02 – Probe Surveillance.

ATMS03 – Surface Street Control

Description

This package provides the control and monitoring equipment, the communication links, and the signal control equipment that support local surface street control or arterial management. Technologies may include static pre-timed control systems, fully automated traffic responsive systems that are dynamic to adjust to current traffic conditions. Inter-jurisdictional systems that do not rely on real-time coordination are represented in this package. (See Figure A-3.)

General Analytical Commentary

This market package has a wide range of benefits serving a number of different customer groups. The evaluator should refer to the appropriate ITS study area in Appendices B through F for guidance based on the selected objective. Additional commentary on operational efficiency studies associated with this market package is provided below.

Analytical Commentary on Changeable Lane Assignment System (CLAS)

Impacts of CLAS on Operational Characteristics of Transportation Infrastructure. Voight and Goolsby studied the potential effects on lane utilization of a CLAS on freeway frontage roads for time-of-day (TOD) operations under recurring congestion conditions, as well as under incident conditions (*1*). CLAS is utilized on city-operated surface streets as well. CLAS addresses signalized intersection approach capacity shortages due to changing turning movement demands by TOD or incident conditions through dynamic lane assignment. Intersection geometrics and signal timing issues must be considered when implementing or evaluating a CLAS. For example, if an exclusive through lane is reassigned to be a shared through/left-turn lane, a protected-only left-turn operation with a "split-phasing" scheme will be required. A protected-only left-turn operation will be required because permissive left turns from dual left-turn lanes are not considered safe operation. A split-phasing operation will be required because through vehicles following a left-turning vehicle in the shared through left-turn lane would be blocked if the signal indication for the left-turning traffic turned red to give the opposing through traffic the right-of-way.

Another example is when a through lane is reassigned to be an exclusive left-turn lane. Intersection geometrics might not permit the opposing left turns to move during the same signal phase or interval when the dual left-turn traffic has the right of way. These types of considerations will affect the overall performance of the intersection and might nullify some of the benefits gained from the dynamic lane assignment capabilities. These issues are less of a concern for one-way frontage road intersections due to their geometric characteristics. With turning movement capacity being dynamically adjusted through the use of CLAS, signal timing parameters such as cycle length and splits might require changing for the overall efficiency of the intersection.

An example of the increase in saturation flow rate that can result from the use of CLAS is discussed here. An approach to a signalized intersection contains one exclusive left-turn lane and two through lanes. Just considering left-turn and lane utilization factors, the saturation flow rate for the left-turn lane group would be:

S= (1900 vphpl) × (1 lane) × (.95) × (1.0) = 1805 vph; where f_{LT} = .95 and f_{LU} = 1.0

In the next scenario, the through lane adjacent to the exclusive left-turn lane is designated as a shared through/left-turn lane via a CLAS operation. The saturation flow rate of the left-turn/shared through left-turn lane group would be:

S= (1900 vphpl) × (2 lanes) × (.96) × (.83) = 3028 vph; where f_{LT} = .96, assuming the proportion of left turns in the lane group is 75 percent, and f_{LU} = 0.83, assuming that Vg = 1000 vph and Vg_1 = 600 vph.

Because the utilization of the two lanes is not perfectly balanced in this example, the saturation flow rate for the lane group with two lanes is less than double the saturation flow rate of the lane group with one exclusive left-turn lane.

A Texas Transportation Institute (TTI) study "Evaluation of the US290 Changeable Lane Assignment System for Incident Management" evaluated the operational effectiveness of implementing a CLAS system as an incident management tool on freeway frontage roads (*2*). Responsive signal timing plans on the frontage road were also a part of the analysis. In general, for simulation studies of this type, the modeling results will vary depending on the location of the incident and length of queue relative to the location of exit ramps. Also, results will vary depending on assumptions made concerning information received by drivers upstream of the incident, the amount of traffic that diverts, and the level of congestion on the frontage roads and cross streets during normal, non-incident conditions.

A summary of some of the results from the US290 study is presented in Table A-1.

Table A-1. Volume Weighted Average Delay per Vehicle (sec) Actual Incident versus Incident Simulated with CLAS.

		Actual Incident		Incident with Simulated CLAS	
Time of Day	**Incident Duration/Lanes Blocked**	**Frontage Delay per Veh (sec)**	**Mainline Delay per Veh (sec)**	**Frontage Delay per Veh (sec) (Change)**	**Mainline Delay per Veh (sec) (Change)**
AM 0800-0845	30 min; 1 lane	20.5	79.2	28.6 (+8.1)	73.2 (-6.0)
Midday	15 min; 2 lanes	38.7	131.3	34.3 (-4.4)	81.5 (-49.8)
Midday	45 min; 2 lanes	39.8	203.4	35.4 (-4.4)	142.8 (-60.6)
PM 1845-1930	30 min; 1 lane	20.8	194.4	29.6 (+8.8)	154.8 (-39.6)
PM 1715-1815	30 min; 1 lane	31.5	138.0	44.4 (+12.9)	121.0 (-17.0)

Impacts of CLAS on Travel Demand Characteristics Route. Diversion to freeway frontage roads or other parallel facilities under incident conditions on the freeway mainline is probably the most likely impact that a CLAS system will have on travel demand characteristics. The level of diversion will depend on several factors including the location of the incident, the perceived amount of travel time savings, and the amount and quality of information given to drivers upstream of the incident.

Analytical Commentary on Responsive or Adaptive Signal Systems

Impacts of Responsive or Adaptive Signal Systems on Operational Characteristics of Transportation Infrastructure. Responsive signal systems will implement a set of previously developed signal timing parameters when changes in traffic conditions are detected. Several sets of signal timing parameters are stored, and the appropriate set is implemented based on traffic conditions. Adaptive signal systems will develop a set of signal timing parameters in real time as traffic conditions change. The signal timing parameters will, in turn, affect the capacity of a given intersection approach or lane group.

A key factor in both systems is the ability to accurately detect and interpret traffic conditions. In addition, there are issues to consider (such as dwelling time, loss of signal coordination) when transitioning from one set of signal timing parameters to another.

Impacts of Responsive or Adaptive Signal Systems on Travel Demand Characteristics. As with CLAS, route diversion to freeway frontage roads or other parallel facilities under incident conditions on the freeway mainline is probably the most likely impact that a responsive or adaptive signal system will have on travel demand characteristics. The level of diversion will depend on several factors including the location of the incident, the perceived amount of travel time savings, and the amount and quality of information given to drivers upstream of the incident.

In addition to the research studies mentioned in the CLAS discussion, there are several more studies found in the literature relevant to evaluating CLAS and Traffic Responsive and Adaptive Signal Systems and that were specifically studied in Texas:

- TTI Research Report 2978-1F; Real-Time Assessment and Use of Arterial Street Capacity for Freeway Diversion Routing; Oct 1996;
- TTI Project Summary Report 2971-S; Evaluation of Innovative Coordination Methods Utilizing ITS Technology for Traffic Signals; Oct 1997;
- Southwest Region University Transportation Center SWUTC Research Report 465080-1F; Incorporating the Effects of Signal Transition in the Selection of Timing Plans in Traffic Responsive Signal Systems; May 1998;

- TTI Research Report 2929-2; Results of Simulation Studies Relating to the Operation of Closed-Loop Systems in a Traffic Responsive Mode; Jan 1997.

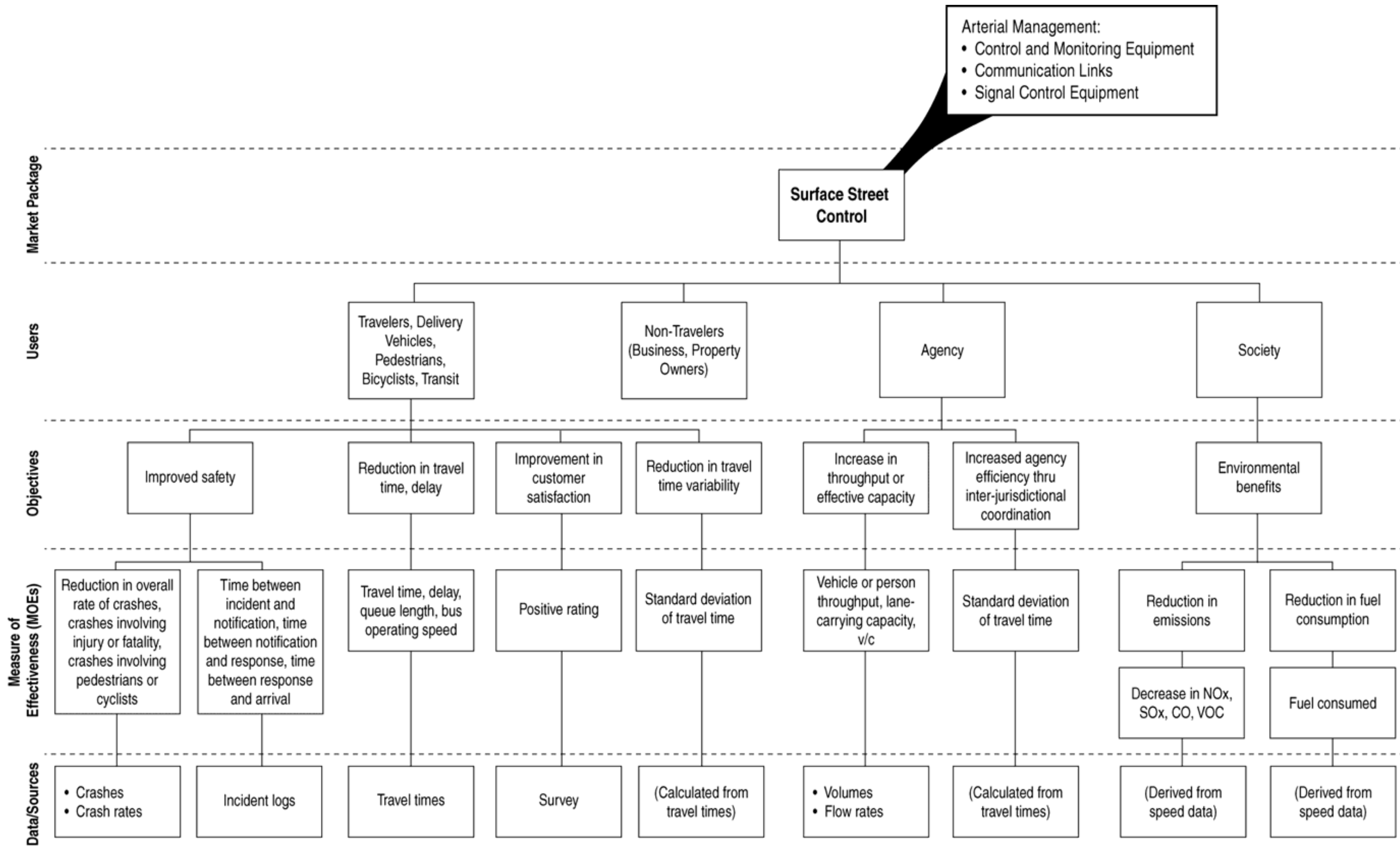

Figure A-3. ATMS03 – Surface Street Control.

ATMS04 – Freeway Control

Description

This package uses the instrumentation of the network surveillance package to support freeway monitoring. The package provides communications and roadside equipment to support ramp control, lane controls, and interchange controls for freeways. Examples of equipment may include: detectors, vehicle transponders or readers, video cameras, adaptive signal systems, or traffic management centers. (See Figure A-4.)

General Analytical Commentary

This market package has a wide range of benefits serving a number of different customer groups. The evaluator should refer to the appropriate ITS study area in Appendices B through F for guidance based on the selected objective. Additional commentary on operation efficiency studies associated with this market package is provided below. Freeway control consists of three components: ramp metering, lane controls, and dynamic message signs.

Analytical Commentary on Ramp Metering

Impacts of Ramp Metering on Operational Characteristics of Transportation Infrastructure. Access to freeway facilities is restricted during ramp-metering operations. In general, freeway traffic density is reduced and freeway lane-changing density and turbulence is reduced at ramp junctions and in weaving areas because vehicle headways for on-ramp traffic is being increased.

Impacts of Ramp Metering on Travel Demand Characteristics. Route diversion to surface streets due to freeway ramp metering is one potential impact on travel demand. The Minnesota Department of Transportation uses ramp meters on approximately 210 miles of freeways in the Twin Cities metropolitan area and has installed 430 ramp meters since 1969 (*3*). In the Fall of 2000 an experiment was conducted whereby ramp meters where shut down for several weeks. Table A-2 and A-3 shows that before the meters were turned off, 70 to 80 percent of the Twin Cities', motorists responded that they sometimes avoided metered ramps by taking an alternate route (*altogether*)[1] or by using another on-ramp. Seventy-five to eighty-five percent responded that they sometimes leave earlier or later to avoid traffic congestion. The Twin Cities survey results support the fact that traffic diversion resulting from ramp metering can consist of spatial diversion and temporal diversion.[2] Modal diversion is also possible.

Table A-2. Diversion Patterns in the "With Ramp Meters" Surveys (*3*).

	Random Samples	I-494 Corridor	I-351 Corridor	I-35W Corridor	I-94 Corridor
Route Diversion					
Sometimes use alternative routes to avoid waiting at ramp meters	65.8%	71.4%	72.0%	72.0%	71.0%
No	31.2%	28.6%	28.0%	28.0%	29.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Time-of-day Diversion					
Sometimes leave earlier to avoid traffic congestion	78.7%	75.4%	78.4%	85.6%	74.8%
No	21.3%	24.6%	21.6%	14.4%	25.2%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Ramp Diversion					
Sometimes avoid a ramp that is backed up with traffic and use a different ramp to enter a freeway	75.1%	77.0%	76.0%	80.0%	79.4%
No	24.9%	23.0%	24.0%	20.0%	20.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

[1] Precise definitions for "route diversion" versus "ramp diversion" could not be found in the Twin Cities report published on-line.
[2] It could not be determined from the on-line report if "temporal diversion," "ramp diversion," and "route diversion" were exclusive categories.

Table A-3. Diversion by Frequent Freeway Users in the "Without Ramp Meters" Surveys (3).

	Random Samples	I-494 Corridor	I-351 Corridor	I-35W Corridor	I-94 Corridor
Route Diversion					
Tried other routes since the ramp meter shutdown	23.3%	45.3%	36.0%	35.7%	41.9%
Always used the same route since the ramp meter shutdown	76.7%	54.7%	64.0%	64.3%	55.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Time-of-day Diversion					
Sometimes left earlier or later to avoid traffic congestion	25.6%	40.2%	33.9%	41.7%	33.1%
Did not leave earlier or later to avoid congestion	74.4%	59.8%	66.1%	58.3%	68.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

The reader might not be able to infer from the national literature what impacts ramp metering diversion will have on the operation of freeway frontage roads as the State of Texas' practice of building frontage roads is unique (*4*). Other issues to consider when interpreting the results from the literature on traffic diversion to surface streets with freeway ramp metering in place are as follows:

- route diversion that occurs in the short-term, some weeks or months immediately following the implementation of ramp-metering operations, versus diversion that occurs over the long-term; and
- diversion of existing trips in the study corridor that were present before ramp metering was implemented versus new trips in the future that are generated after ramp metering has been implemented, i.e., what route would a new trip have taken if the ramp-metering operation had not been implemented.

Kang and Gillen (*5*) reported that empirical results suggest that 5 to 10 percent of vehicles will be diverted. Wu (*6*) cited several studies that suggested that significant diversion under freeway ramp-metering operations was required in order to improve the overall system delay. In another study cited by Wu concerning trip diversion, Stephanedes (*7*) surveyed 1100 commuters in the south I-35W corridor of the Twin Cities Metropolitan Area. The survey indicated the following:

- *Diversion decision at the trip origin* was a function predominantly of trip time in addition to route length and number of intersections along the trip.
- *Diversion decision at freeway entrance ramps* depended on the perceived trip time on the freeway and arterial and the perceived waiting time at the ramp queue.

Analytical Commentary on Lane Control Signals (LCS)

Impacts of Lane Control Signals on Operational Characteristics of Transportation Infrastructure. LCS are used to inform motorists the status of a travel lane ahead (open or closed). This information is provided so that when a lane(s) is closed ahead, vehicles can begin to transition out of the affected lane. The use of LCS in this regard, involves a tradeoff between smooth lane changing and capacity underutilization (*8*). In a MIT study, the overall impact on travel time for compliant and non-compliant drivers was determined to be a function of length of LCS corridor, traffic volumes-lane use pattern, and compliance rate (*8*). Use of LCS to facilitate smooth merging into the adjacent lane is also associated with improving vehicle speed uniformity (*9*).

LCS can also be utilized as part of various managed lanes operations such as:

- temporary shoulder utilization,
- reversible lane operations,
- HOV priority treatments, and
- truck restrictions.

Empirical data regarding LCS impacts on lane-changing characteristics of motorists were difficult to find. A TTI study, *Yellow Transition Lane Control Signal Symbols for Freeway Traffic Management* (*10*), contains some empirical data on this subject.

Impacts of Lane Control Signals on Travel Demand Characteristics. Route diversion is the only possible impact LCS might have on travel demand characteristics. No empirical data on route diversion solely due to LCS operation could be found.

Analytical Commentary on Dynamic Message Signs (DMS, CMS, VMS)

Dynamic message signs provide en route guidance and information. For example (*11*):

- current traffic conditions: speeds, incident locations, other congestion locations;
- weather effects: pavement conditions, road closures;
- route guidance around incidents or special events; and
- lane/shoulder/ramp use status.

TTI Research Report 1882-2 contains specific recommendations concerning DMS issues in the following four categories (*12*):

1. communicating time and day for future roadwork to motorists,
2. motorists' interpretations of specific words or phrases used on DMS,
3. DMS operating practices, and
4. using DMS with lane control signals.

Report 1882-2 states, "To be effective, a DMS must communicate a meaningful message that can be read and comprehended by motorists within a very short time period (constrained by the sight distance characteristics of the location and design features of the DMS). Since DMSs represent many motorists' primary concept of intelligent transportation systems, improperly designed or operated DMSs will have a negative impact on the public's perception of ITS in general. It is imperative, therefore, that the content, format, and application of information on the DMS are of the highest possible quality and consistency statewide (*12*)."

Impacts of Dynamic Message Signs on Operational Characteristics of Transportation Infrastructure. CMS operation has the potential to impact lane-changing characteristics by providing information to motorists about downstream conditions that require vacating a lane (e.g., incident, debris, construction). Empirical data regarding CMS impacts on lane-changing characteristics of motorists were difficult to find. A TTI study, *Yellow Transition Lane Control Signal Symbols for Freeway Traffic Management*, contains some empirical data on this subject (*10*). CMS operation can also impact vehicle speeds.

Impacts of Dynamic Message Signs on Travel Demand Characteristics. The obvious potential travel demand impact of CMS is route diversion. Table A-4 is a summary of documented driver responses to CMS taken from an ITS Decision Report (*13*) (California PATH).

Table A-4. Driver Response to VMS.

	Driver Response
Paris	According to the investigation of effects of VMS on link flow based on loop detector data in Paris, the important findings were: the VMS could affect vehicle diversion significantly, especially during congested times; VMS had more influence to drivers during morning peak hours than during evening peak hours; the longer the queue length posted in VMS, the more drivers diverted.
Virginia	Surveys of drivers' attitudes toward VMS in Virginia found [Benson, 1996]: no significant correlation between drivers' attitudes and demographic variables such as age, education, income, sex; When asked how often they were influenced by VMS, half of the people surveyed responded with '"often," two-fifths "occasionally," and others "not at all." More than one-third of people said that the information on VMS was sometimes inaccurate or out-of-date; three-fifths of the surveyed people said that they would choose the alternative route recommended by VMS; 97 percent of people supported the accident message on VMS such as "accident ahead"; half of the people liked the information of estimated delay time; two-thirds liked the safety message such as "drive to survive."
INFORMS	In an evaluation of INFORMS: 96 percent of people said that they had seen the VMS; 29 percent and 46 percent regarded the sign very useful and moderately useful; 7 percent and 56 percent indicated that the information was always accurate and usually accurate; 45 percent said they diverted to the alternative route in response to VMS, and 5 percent said they never changed their routes in this way. In a typical incident, 5 to 10 percent of mainline traffic in INFORM diverted to several upstream off ramps, based on the passive messages (no recommended alternative route); and the percents varied widely based on the availability of alternative routes, severity of the incident, and other factors. The diversion percentage increased as the directness and excess capacity of the alternative route increased.
Virginia	The study of the effectiveness of VMS in work zones [Garber, 1996] and testing of VMS at seven sites on interstate highways in Virginia [Garber, 1995] showed that the changeable messages sign with a radar unit was more effective than the static MUTCD (Manual on Uniform Control Devices, FHWA, U.S. Department of Transportation, Washington, DC, 1988) signs in altering driver behavior in work zones. The use of a personalized message to the high-speed drivers made the drivers more willing to reduce speeds in these work zones; both speeds and speed variance could be reduced through the use of VMS, thus the safety in work zones was increased.
Finland	Based on the survey results in Finland [Rama et al. 1997]: 91 percent of the drivers recalled the posted speed limit, 66 percent recalled the slippery road sign, and 34 percent recalled the temperature display, indicating that the drivers could recall the VMS better than the regular (fixed) signs.
South Dakota	A study of speed monitoring displays with radar in work zones at South Dakota indicated that they were effective in reducing the speed of the traffic entering the work zone. The mean speeds were 6 to 8 km/hr (4 to 5 mi/hr) lower after the speed monitoring displays were installed. The speeds of vehicles exceeding the speed limit of the work zone were reduced significantly, and the number of vehicles exceeding the speed limit by 16 km/hr (10 mi/hr) was reduced by 40 percent. The speed monitoring displays with radar were more effective than radar alone, which resulted in reductions in mean speeds of only 2 to 3 km/hr (1 to 2 mi/hr), and the number of vehicles exceeding the speed limit by 16 km/hr (10 mi/hr) of only 10 percent.
Virginia	A survey by VDOT [VDOT, 1995] showed that local commuters most often sought road and travel information from the winter travel advisory phone. The primary source for interstate truckers was CB radio. Nonetheless, the VMS was indicated as an important source by almost 70 percent of local commuters and 40 percent of the interstate truckers surveyed.
Dallas	When VMS were used for special event in Dallas, 71 to 85 percent of the drivers used the recommended route. Reasons given by the 15 to 29 percent that did not divert were 1) didn't see or understand the message; 2) anticipated unsatisfactory traffic conditions on the alternate route; 3) were unfamiliar with the alternate route or uncertain of the adequate guidance along the route; 4) lacked confidence in the information. Source: [Dudek, 1992]
Houston	The results of a survey taken to see the response of residents and drivers to information on the VMS boards showed that 73 percent felt "The incident and travel time information was useful," 80 percent felt "The incident and travel time information was accurate," 53 percent said "I altered my travel patterns in some way because of the information," and 33 percent said "I changed my travel route because of information." Source: [Dudek, 1996]

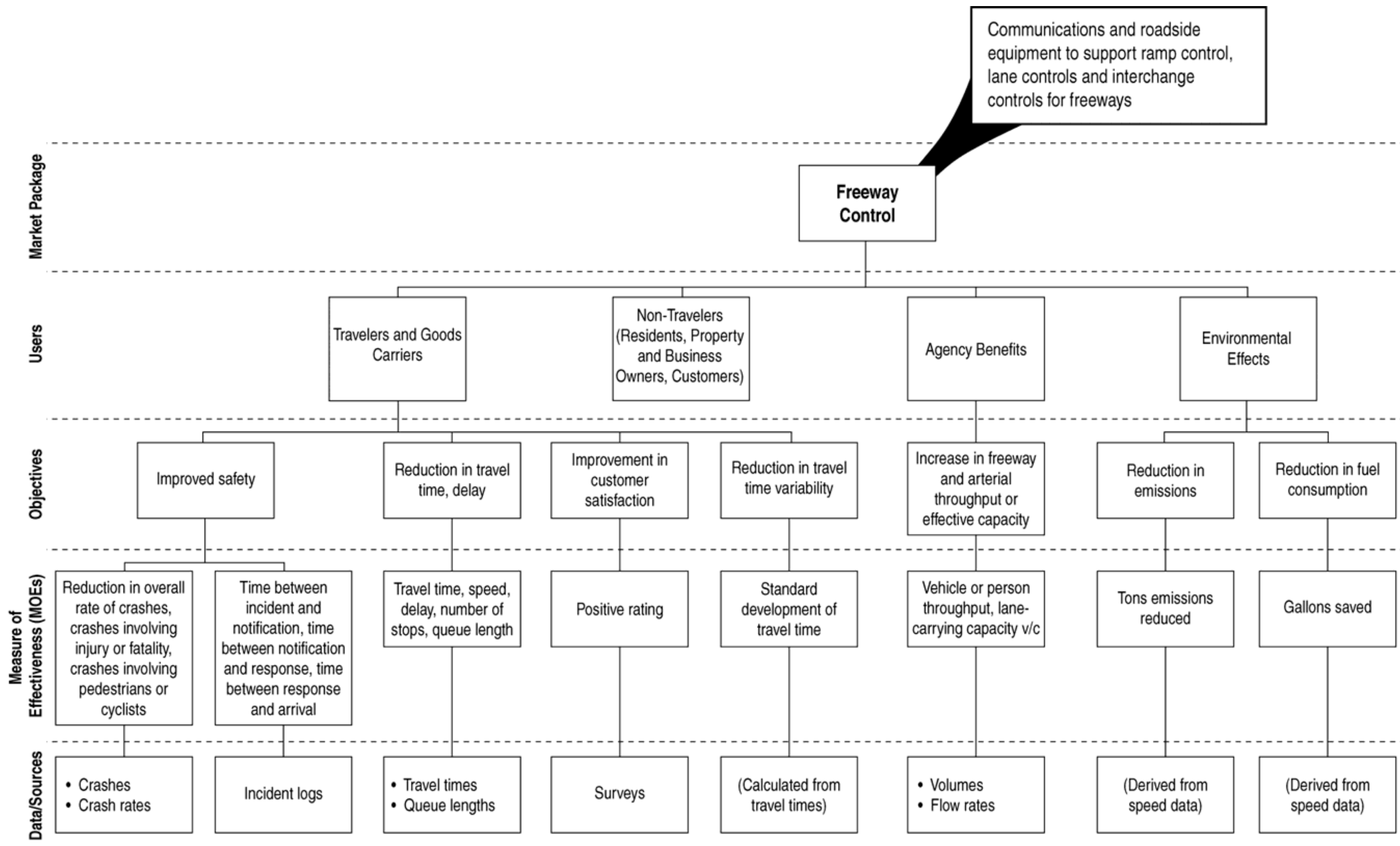

Figure A-4. ATMS04 – Freeway Control.

ATMS05 – HOV Lane Management

Description

This market package manages high-occupancy vehicle lanes by coordinating freeway ramp meters and connector signals with HOV lane usage signals. Preferential treatment is given to HOV lanes using special bypasses, reserved lanes, and exclusive rights of way. These treatments may vary by time of day. Vehicle occupancy detectors may be used.
(See Figure A-5.)

Analytical Commentary

Potential HOV lane management technologies such as lane control signals, VMS, CCTV, and automated vehicle identification (AVI) (high-occupancy toll lanes) provide en route guidance, incident detection and verification, enforcement capabilities, and increases in toll booth effective capacity. These individual ITS technologies and their impacts on operational characteristics of traffic flow and impacts on travel demand characteristics are discussed in other market package sections. The potential impacts of implementing an HOV lane in a freeway corridor will be discussed here.

Impacts of HOV Lanes on Operational Characteristics of Transportation Infrastructure. Concerning the overall operational characteristics of a freeway facility, the HOV facility's implementation could impact the number and intensity of lane-changing maneuvers on the freeway facility depending on design and operational characteristics of the HOV facility such as:

- facility's location (inside or outside),
- amount and frequency of access/egress provided, and
- origin and destination of vehicles utilizing the HOV facility.

Other issues concerning the operational characteristics of a freeway facility when an HOV lane is implemented include:

- volume-to-capacity ratio of the HOV lane versus volume-to-capacity ratio for the general-purpose lanes;

- availability of a shoulder lane for disabled vehicles to pull over on the HOV facility, as well as the general-purpose lane facility; and
- presence of ramp metering and ramp meter bypass for HOVs.

Impacts of HOV Lanes on Travel Demand Characteristics. Potential impacts of an HOV facility on travel demand characteristics include the following:

- **Mode choice –** Mode changes from single-occupant vehicles (SOVs) to carpools, vanpools, and buses, thereby increasing the overall vehicle occupancy of the freeway facility. In an annual TTI report entitled "Evaluation of High-Occupancy Vehicle Lanes in Texas, 1997" the combined HOV and general-purpose lanes peak-hour average vehicle occupancy has generally increased from pre-HOV implementation on freeway facilities in Houston and Dallas (*14*). Increases on freeway facilities are summarized in Table A-5.

Table A-5. Changes in Peak-Hour Average Vehicle Occupancy (Combined Freeway and HOV Lane Data) (*14*).

Freeway Facility	Pre-HOV Lane Implementation	Post-HOV Lane Implementation (1997)
Katy	1.26	1.47
North	1.28	1.51
Northwest	1.14	1.35
Southwest	1.16	1.30
Gulf	1.29	1.29
E RLT	1.35	1.37
Stemmons	1.11	1.24

- **Route choice –** There is potential for route diversion of existing carpools (pre-HOV facility implementation) from parallel routes to an HOV facility. Data from Houston and Dallas indicate that the percent of total carpools using an HOV lane that diverted from a parallel route ranged from 2 to 9 percent in data collected in 1990 and 1994.

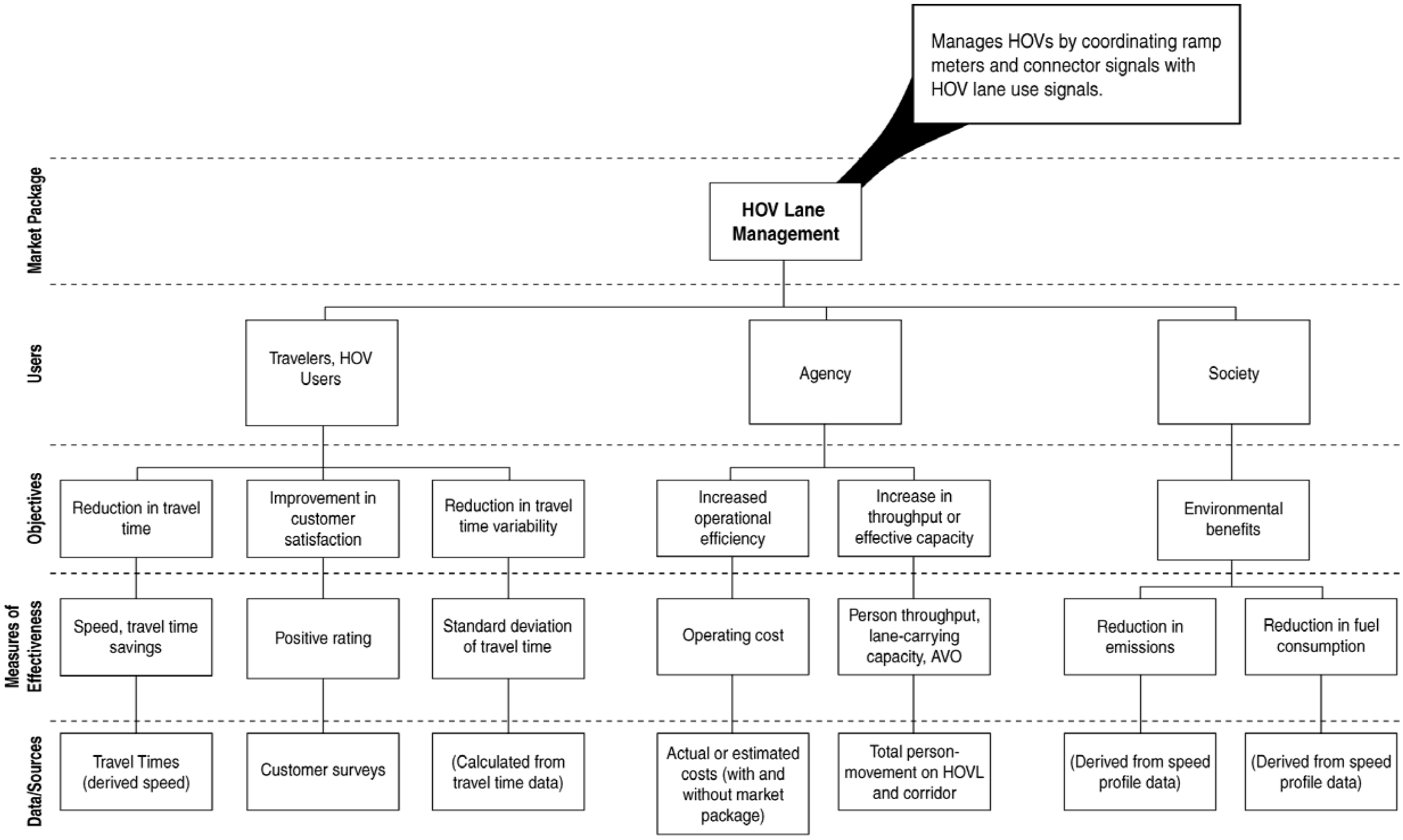

Figure A-5. ATMS05 – HOV Lane Management.

ATMS06 – Traffic Information Dissemination

Description

This market package allows for information to flow to drivers and vehicles via roadway information such as dynamic message signs or highway advisory radio. Ideally, the roadway equipment is strategically located to allow drivers to adjust their routes according to the new information. (See Figure A-6.)

Analytical Commentary

Impacts of Traffic Information Dissemination on Operational Characteristics of Transportation Infrastructure. To the extent that impacts on travel demand characteristics impact the number of vehicles on a particular route(s) during a given time period, potential impacts of pre-trip traffic information dissemination on the operational characteristics of the transportation infrastructure include impacts on the volume-to-capacity ratio.

To the extent that emergency vehicle operators modify their routes based on the traffic information they receive, emergency vehicle signal preemption and its effect on signal operations on the new route is a potential impact.

Impacts of Traffic Information Dissemination on Travel Demand Characteristics. Potential impacts on travel demand characteristics of pre-trip information dissemination include temporal diversion, route choice, and mode choice. The analyst should consider existing (pre-ITS deployment) sources of traffic information dissemination and their potential impacts on travel demand characteristics when evaluating the impacts of an ITS deployment.
In lieu of attempting to predict the number of persons who will utilize traffic information pre-trip or en route, some studies evaluating the potential impacts of traffic information dissemination have conducted sensitivity analyses of the percent of persons who have access to pre-trip or en route information and act upon the information received, thereby impacting their travel characteristics (*15*). As the number of persons who have access to traffic information increases, the overall impact on a corridor can diminish or become negative.

Pre-trip traffic information dissemination can result in travelers deciding to use their normal route rather than diverting to a possible alternate route, provided they are confident with the accuracy of the information they are receiving (*16*).

A Mitretek Systems presentation suggests that commuters using ATIS will experience a larger percentage of on-time reliability and just-in-time reliability (on-time and <10 minutes early) than non-ATIS users, and that travel time reliability is the major impact of utilizing ATIS rather than travel time savings (*17*).

In a Thanksgiving Day holiday travel survey, about 25 percent of holiday travelers in the I-95 Northeast Corridor who had pre-trip traffic information changed their routes based on pre-trip information concerning construction, special events, or some other problem (*18*). About 33 percent of the holiday travelers changed the time they traveled (temporal diversion). The results of this survey support the notion that ITS technologies will have their largest impacts during non-recurring congestion conditions such as holiday travel.

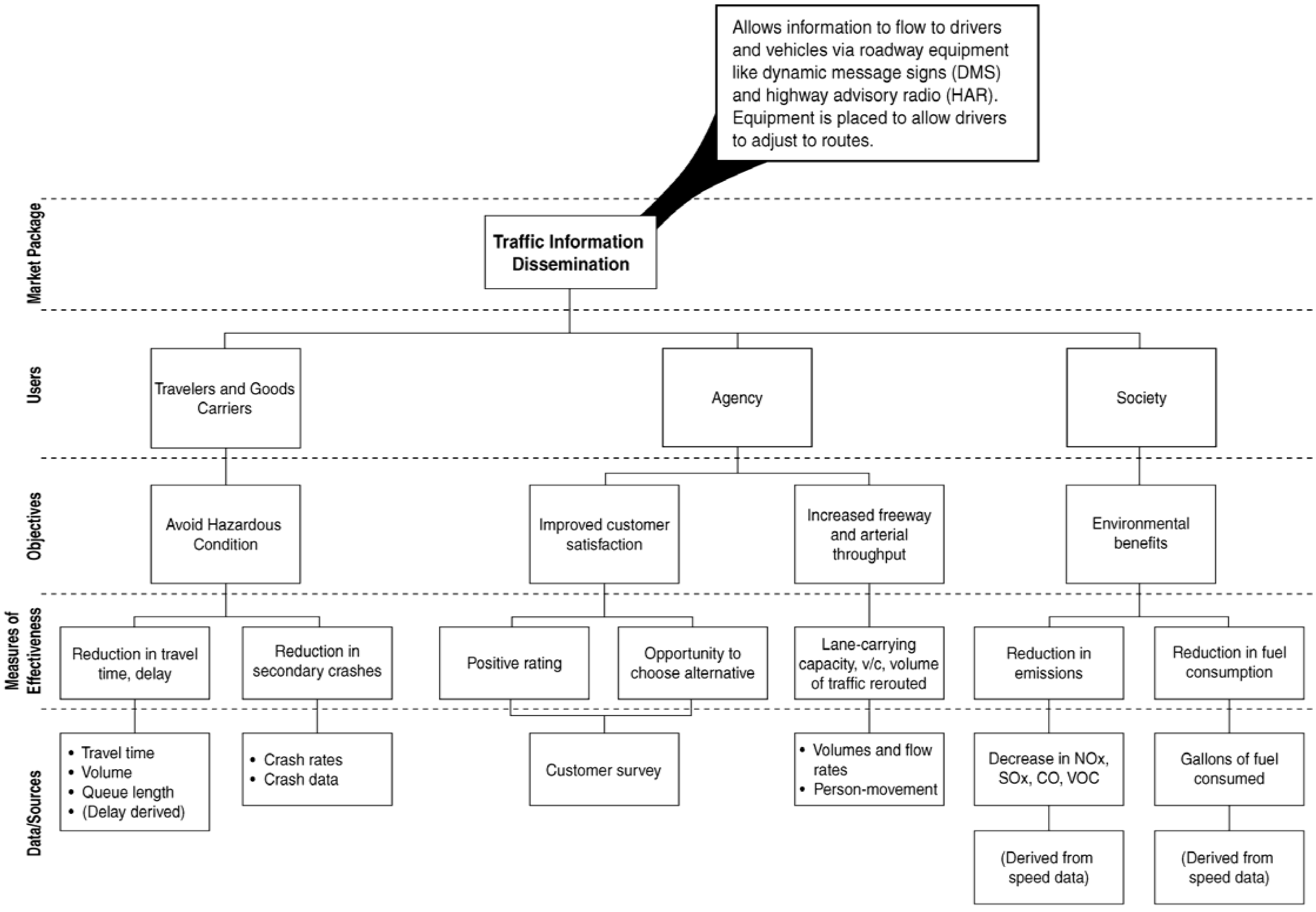

Figure A-6. ATMS06 – Traffic Information Dissemination.

ATMS07 –Regional Traffic Control

Description

This market package enhances the surface street control and freeway control market packages by adding the communications links and integrated control strategies that enable integrated regional traffic control across jurisdictions. Use of the regional traffic control market package touches upon three levels of ITS integration: institutional integration (sharing of information), infrastructure integration (sharing of communications networks and data storage facilities), and integration of control (agencies can control shared components). (See Figure A-7.)

Analytical Commentary

Benefits of this market package accrue primarily to the agency. Regional traffic control supports the combination of surface street control and freeway control market packages. The evaluator should refer to the institutional benefits study area (Appendix F) for guidance.

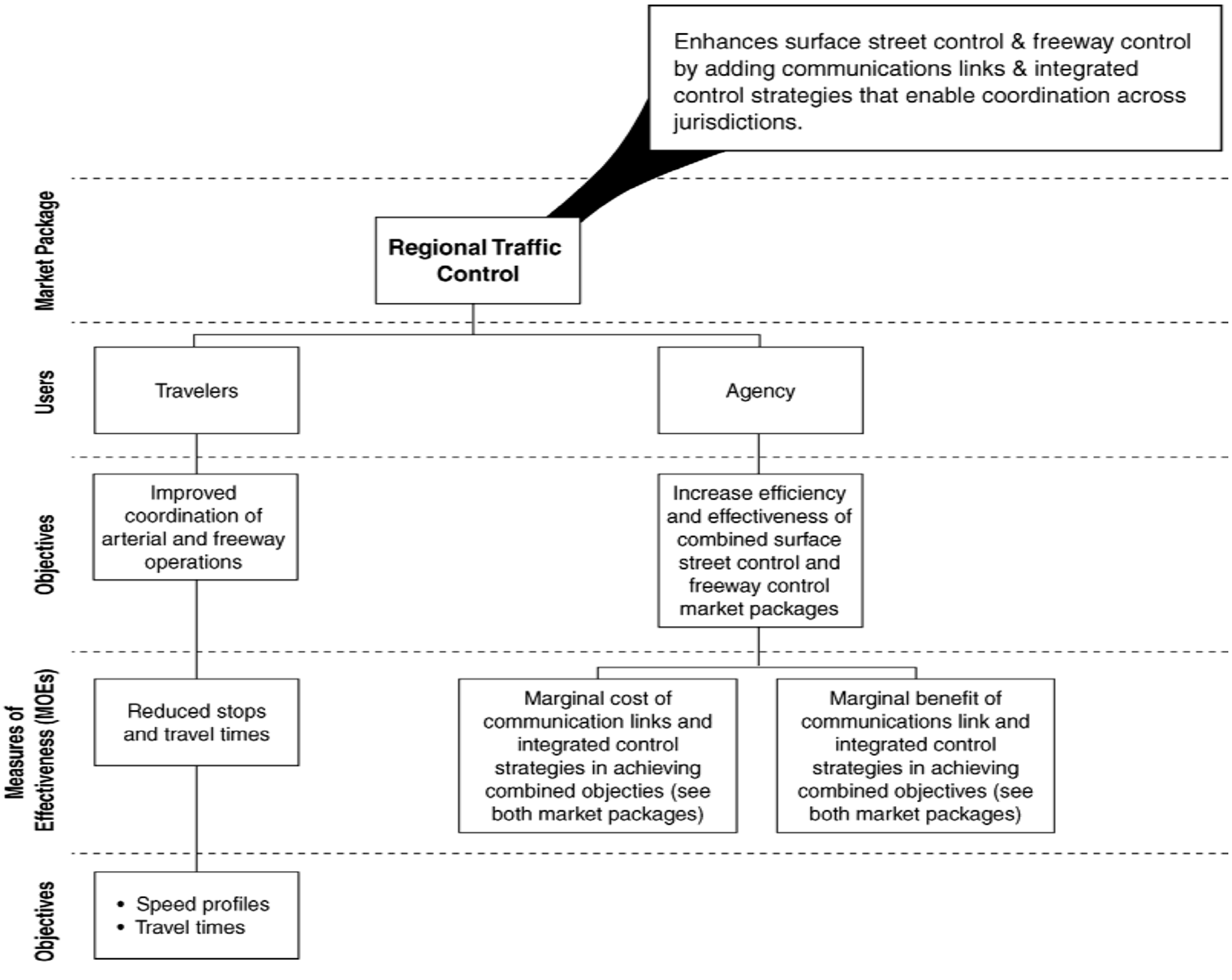

Figure A-7. ATMS07 – Regional Traffic Control.

ATMS08 – Incident Management Systems

Description

This package manages both planned and unexpected incidents on the transportation network. The package includes incident detection capabilities through roadside surveillance, regional coordination with traffic management centers, maintenance and construction management, and emergency management centers. Information is used to detect and verify incidents. It also includes presentation of information to affected travelers using the traffic information dissemination package and broadcast traveler information package. (See Figure A-9.)

Analytical Commentary

Figure A-8 summarizes the five major phases of an incident – detection, verification, response, clearance, and queue dissipation. Different ITS technologies are designed to address these incident phases or characteristics. The impacts that incident management technologies have on the operational characteristics of transportation infrastructure and on travel demand characteristics are summarized in Table A-6 (*19*).

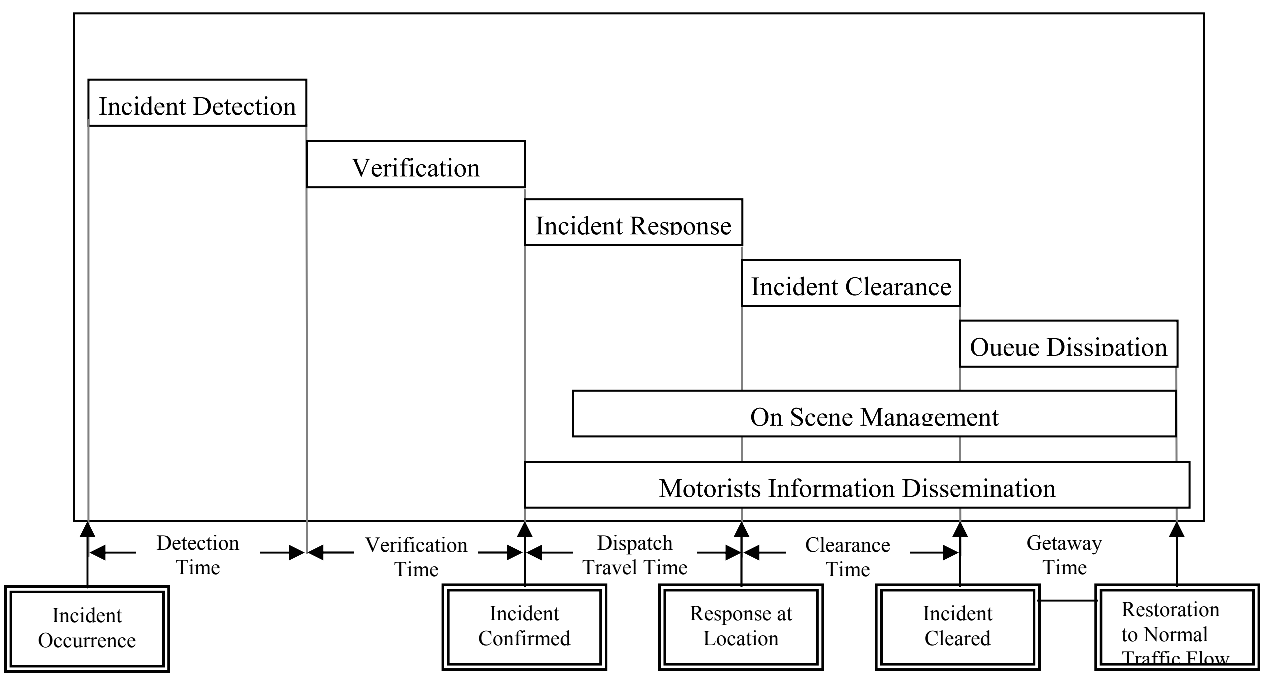

Figure A-8. Five Major Phases of Incident Management.

Table A-6. Impacts of Incident Management System.

Incident Management System Technology	Impacts on Operational Characteristics of Transportation Infrastructure	Impacts on Travel Demand Characteristics
CCTV, Loop Detectors, Algorithms	Time to detect and verify incident	-
Freeway Service Patrol (FSP)	Time to respond to an incident; time to clear an incident	-
CMS, LCS	See ATMS04 – Freeway Control	See ATMS04 – Freeway Control

When evaluating operational efficiency (or other study areas) impacts of incident management programs, it is helpful to understand the basic nature and characteristics of incidents as summarized in the research literature. If extensive local data on incidents have been collected (type, duration, frequency, lateral location, effective capacity on adjacent lanes, etc.), it should supplant the national data.

Cambridge Systematics, Inc. (along with Harry Cohen and Science Applications International Corporation) developed "Sketch Methods for Estimating Incident-Related Impacts" in a final report dated December 1998 (*20*). In Appendix E of the Cambridge Systematics report, several tables on pages E-8 through E-13 describe the basic nature and characteristics of incidents as found in the literature or developed by the authors of the report (*20*). Table A-7 through A-9 reproduce information from three of these tables concerning incident durations and incident rates.

The term "incidents" refers to crashes as well as vehicle disablements. Crash rates have been shown to vary with volume-to-capacity ratios while the rate of occurrence on a per million vehicle mile traveled basis (MVMT) of types of disablements varies considerably.

Table A-7. Incident Durations (minutes).

V/C Ratio	Accident Rate per MVMT
0-0.70	1.344
0.71-0.90	1.531
0.91-1.00	1.884
GT 1.00	2.038

Table A-8. Crash Rate per MVMT as a Function of Volume-to-Capacity Ratio.

Incident Type	Incident Rate per MVMT
Abandoned	1.968
Accident	(varies with V/C)
Debris	0.219
Mechanical	2.164
Stalled	1.656
Tire	1.552
Other	0.989

Table A-9. Incident Rate per MVMT by Incident Type.

	Incident Location			
	Shoulder		In-Lane	
Incident Type	Mean	Std. Dev.	Mean	Std. Dev.
Accidents	39.7	33.4	47.1	40.2
Mechanical/Electrical	41.4	30.6	38.7	30.5
Tires/Stalled Vehicles/Other	38.2	36.1	34.7	26.6
Abandoned/Debris	31.3	39.5	29.6	34.0

Table A-10 (*21*, *22*) summarizes estimates of effective capacity reduction as a function of type of incident (crash or disablement) and as a function of incident location (on shoulder or blocking lane).

Table A-10. Percentage of Freeway Section Capacity Available Under Incident Conditions.

Number of Freeway Lanes in Each Direction	Shoulder Disablement	Shoulder Accident	Lanes Blocked		
			One	Two	Three
2	0.95	0.81	0.35	0	N/A
3	0.99	0.83	0.49	0.17	0
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.25
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

Table A-11 lists several studies found in the literature review on incident management and estimated reduction in incident response time. The duration of an incident includes incident detection, verification, response, clearance, and queue dissipation. Care must be taken when interpreting reported results of incident management programs. A percent reduction in one of the components of the total incident duration is not equivalent to a percent reduction in the total incident duration. Additionally, "incidents" can be categorized as either crashes or vehicle disablements, with sub-categories in each heading. The average total duration of various types of incidents and the effective capacity reduction of various types of incidents are not uniform.

Table A-11. Summary of Selected Literature on Impacts of Incident Management.

Study or Report	Location and ITS Technology	Reported Incident Management Impacts on Incident Duration	Reported Capacity Reduction Due To Incident
Before-and-After Analysis of Advanced Transportation Management Systems; TTI RR 1467-3; Sep 1997	San Antonio TransGuide Advance Transportation Management System-Phase I (CMS, LCS, loop detectors, and surveillance cameras)	Reduction in response time; 6 min for a minor crash; 5 min for a major crash	Not reported
Evaluation of the Highway 401 COMPASS Freeway Traffic Management System (Renforth Drive to Warden Avenue) Summary Report; Ontario Ministry of Transportation, Canada; Jan 1994	Toronto Highway 401 COMPASS Freeway Traffic Management System (vehicle detection stations (VDS), CCTV, CMS)	Reduction in total duration of average incident; from 86 min to 30 min (a 56 min reduction)	Not reported
Calculating Benefits for NAVIGATOR Georgia's Intelligent Transportation System; Georgia DOT; Sep 1998	Georgia NAVIGATOR Intelligent Transportation System; I-75 and I-85; (Incident Detection System, Highway Emergency Response Operators (HEROs) that patrol facilities and initiate measures to respond, Surveillance Cameras)	Reduction in total duration of average incident; from 64 min to 41 min (a 23 min reduction)	HERO Data
1997 CHART Benefits Evaluation study conducted for Maryland State Highway Administration (MSHA) by the Civil Engineering Department of the University of Maryland at College Park and MSHA staff.	Maryland CHART Incident Management Program (A statewide operations center (SOC) with three satellite traffic operations centers (TOC) and incident response teams; no incident detection; no surveillance cameras)	**1997 Incident Duration** **Incidence Clearance Duration** On average, incident clearance time reduced from 68 min to 45 min (a 23 min reduction)	**CHART Capacity Reduction**
Evaluation of the Southeastern Wisconsin TIME Program – Phase I; University of Wisconsin-Madison; Sep 2000	Wisconsin Gateway Patrol Program (roving tow-trucks to help disabled vehicles with minor on-site repairs or towing vehicle away to "Crash Inspection Site"; daily veh-hrs of operation 13 to 15; daily veh-miles traveled 463 to 529)	Reduction in Incident Response and Clearance time from 50 min to 24 min (a 26 min reduction)	Not reported
Evaluation of the Freeway Service Patrol in Los Angeles; California PATH Research Report UCB-ITS-PRR-98-31; Sep 1998	Los Angeles Freeway Service Patrol; studied 7.8 mile section of I-10; 93 incidents per MVMT; average 3.6 service patrol trucks per 9.8 centerline miles; average number of service hrs per beat = 7.8 hours (assumed per weekday). A beat is a freeway corridor that is patrolled; 40 total beats; average beat length is 9.8 centerline miles.	**Incident Duration Times With FSP** **Incident Duration Times Without FSP** **Incident Response/Clearance Times With FSP** **Incident Response/Clearance Times Without FSP** Reporting a 3.2 minute reduction in average response and clearance time for assisted crashes (from 35.6 min to 32.4 min); Reporting a 11.5 minute reduction in average response and clearance time for vehicle breakdowns (30.5 min to 19.0 min)	Approximately 10% of all incidents were blocking travel lanes (page iv). **Incident Classification** **Incident Tree**

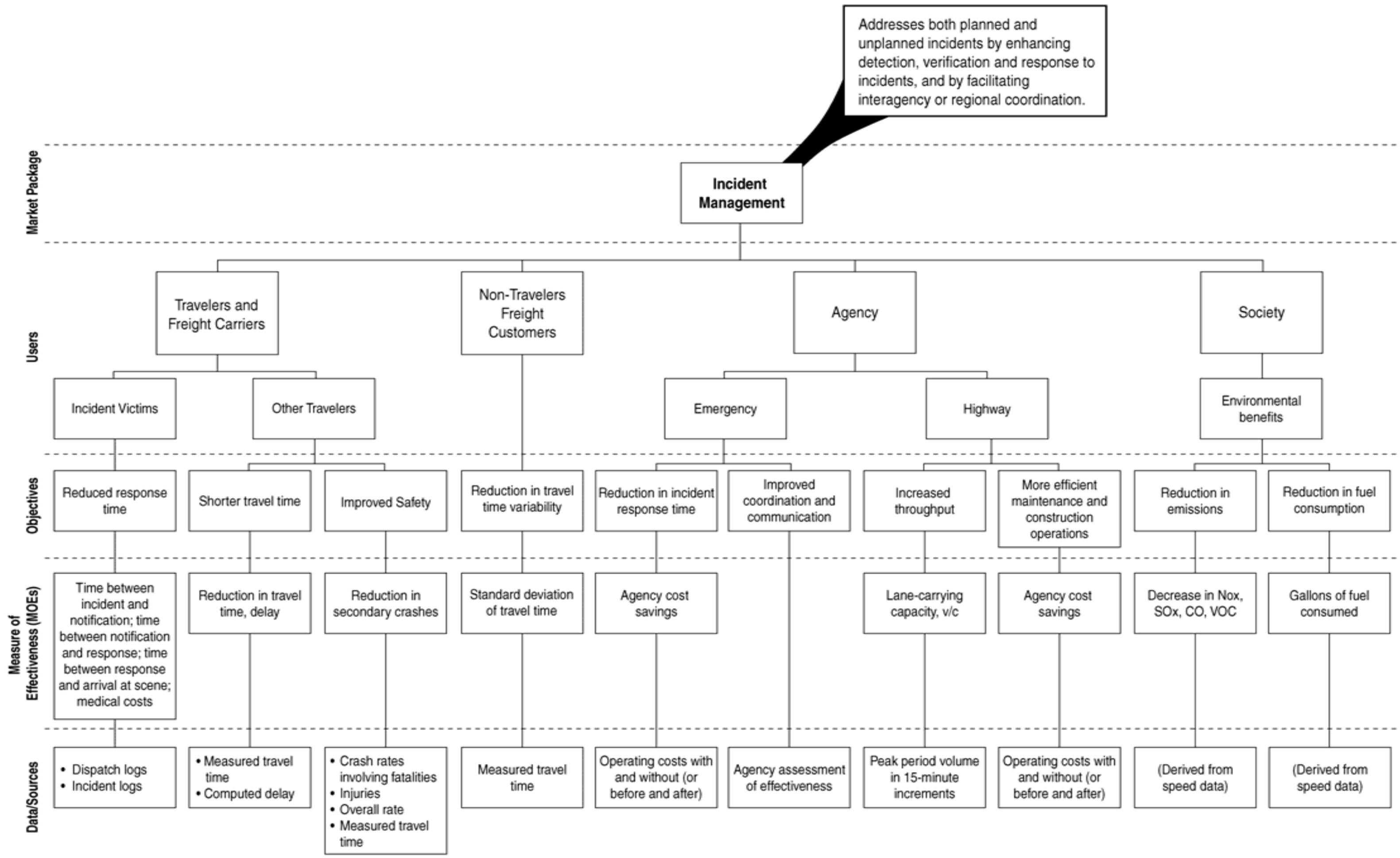

Figure A-9. ATMS08 – Incident Management Systems.

ATMS10 – Electronic Toll Collection

Description

This market package provides toll operators with the ability to collect tolls electronically and detect and process violations. The fees that are collected may be adjusted to implement demand management strategies. Standards, inter-agency coordination, and financial clearinghouse capabilities enable regional and, ultimately, national interoperability for these services. The toll tags and roadside readers that these systems utilize can also be used to collect road use statistics for highway authorities. These data can be collected as a natural by-product of the toll collection process or collected by separate readers that are dedicated to probe data collection. (See Figure A-10.)

Analytical Commentary

Impacts of Electronic Toll Collection on Operational Characteristics of Transportation Infrastructure. Capacity of manual lane versus an AVI lane at a tollbooth as a function of AVI technology is summarized in Table A-12 (*21*). The capacity of a manual lane is based upon an average of several facilities: manual normal, manual no change, manual ticket, manual coin, and manual token.

Table A-12. Approximate Capacities of Toll Lanes.

Toll Collection Method	Passing Speed	Capacity (vphpl)
Manual	Very Slow	770
AVI-Optical Scanner	Slow	1200
AVI-Inductive Loop	Moderate	1400
AVI-Radio Frequency	Fast	1600

Impacts of Electronic Toll Collection on Travel Demand Characteristics. To the extent that ETC makes a route more attractive and drivers decide to divert to that route, ETC could have an impact on travel demand characteristics such as route choice. To the extent that ETC gives HOVs and transit vehicles an advantage over SOVs, ETC could affect mode choice.

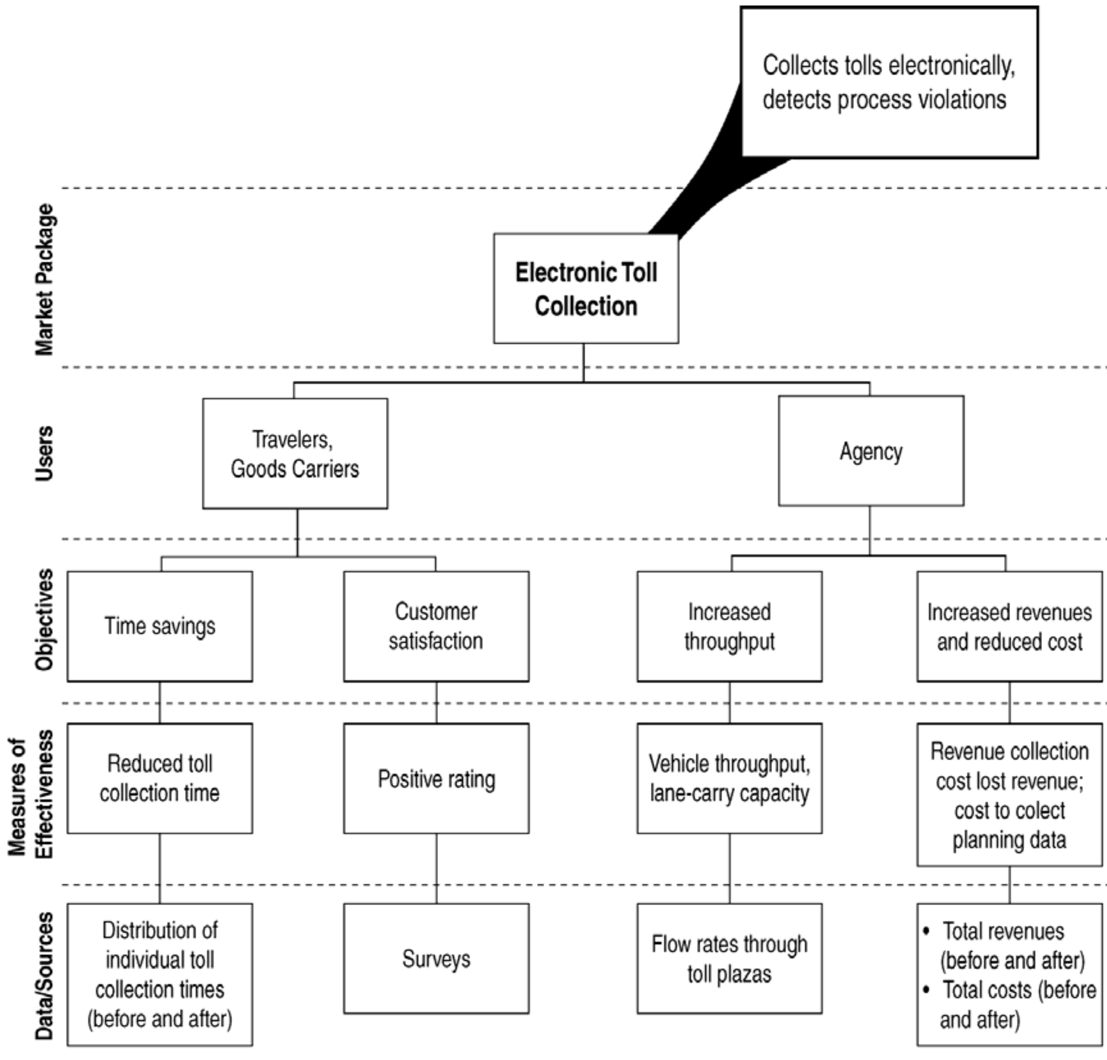

Figure A-10. ATMS10 – Electronic Toll Collection.

ATMS13 – Standard Railroad Grade Crossing

Description

This market package manages highway traffic at highway-rail intersections. Both passive and active warning systems are supported. The warning systems may be supplemented with other standard traffic management devices. The equipment may also interface with adjacent signalized intersections. (See Figure A-11.)

Analytical Commentary

This market package has a range of benefits serving several different customer groups. The evaluator should refer to the safety ITS study area (Appendix C) or the institutional benefits study area (Appendix F) for guidance based on selected objective(s).

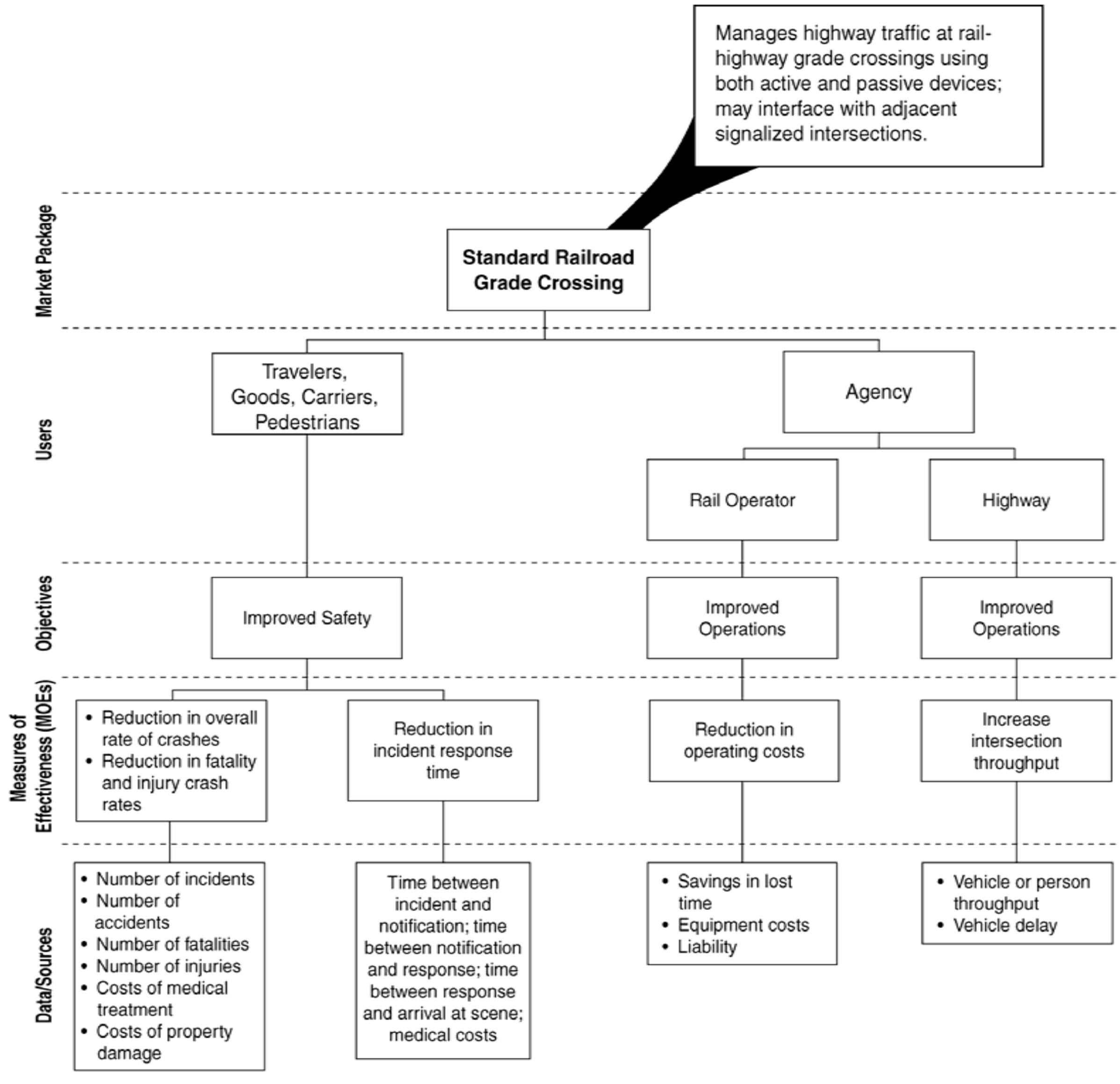

Figure A-11. ATMS13 – Standard Railroad Grade Crossing.

ATMS18 – Reversible Lane Management

Description

This market package provides for the management of reversible lane facilities. The package includes surveillance equipment and sensory equipment to detect wrong-way vehicles. The package includes the field equipment, physical lane access controls, and associated control electronics that manage and control these special lanes. This market package also includes the equipment used to electronically reconfigure intersections and manage right-of-way to address dynamic demand changes and special events. (See Figure A-12.)

Analytical Commentary

Impacts of Reversible Lanes on Operational Characteristics of Transportation Infrastructure. The impact that a reversible lane has on the operational characteristics of a freeway facility is to provide an additional lane of capacity in the direction of travel with an overwhelming proportion of the two-way traffic demand. Consequently, one lane of capacity is removed from the opposite direction of travel.

An important operational issue in the implementation of a reversible lane on a surface street is the provision for left-turning traffic in either direction. For example, consider a four-lane arterial with left-turn bays at intersections. Because the lane adjacent to the roadway centerline in the direction of minor flow is being reversed, the left-turn bays in the minor direction will be removed.

With only one lane remaining in the minor direction, there will be no provision for left-turning vehicles unless there is space for the through lane to be shifted toward the curb. Without a left-turn lane, a left-turning vehicle will block traffic behind it until there is a sufficient gap in the traffic in the opposite direction. Another important consideration for the direction of travel that has been reduced to one lane is the operation of emergency vehicles and transit vehicles. The need for lateral relocation of signal heads during reversible lane operation is another operation issue to consider.

Impacts of Reversible Lanes on Travel Demand Characteristics. Reversible lane impacts on travel demand characteristics include:

- **Route choice** – Motorists divert to the reversible lane facility if the travel time savings is perceived large enough to justify changing routes.
- **Mode choice** – If the reversible lane produces significant improvements in transit operations or if the reversible lane is restricted to HOVs, more person trips might be taken in carpools, vanpools, and transit.

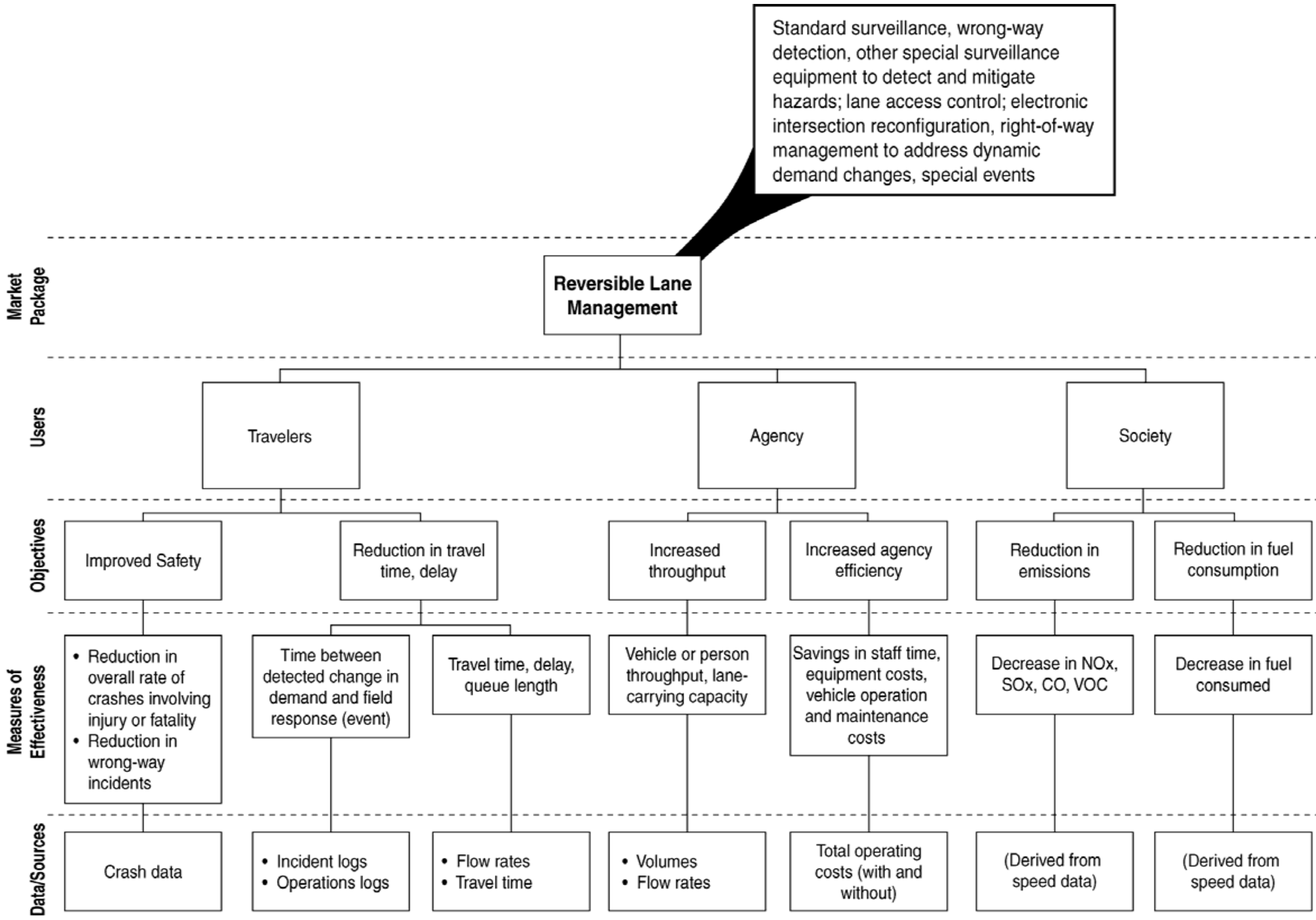

Figure A-12. ATMS18 – Reversible Lane Management.

APTS7 – Multi-Modal Coordination

Description

This market package establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Multi-modal coordination between transit agencies can increase traveler convenience at transfer points and also improve operating efficiency. Coordination between traffic and transit management is intended to improve on-time performance of the transit system to the extent that it can be accommodated without degrading overall performance of the traffic network. More limited local coordination between the transit vehicle and the individual intersection for signal priority is also supported by this package. (See Figure A-13.)

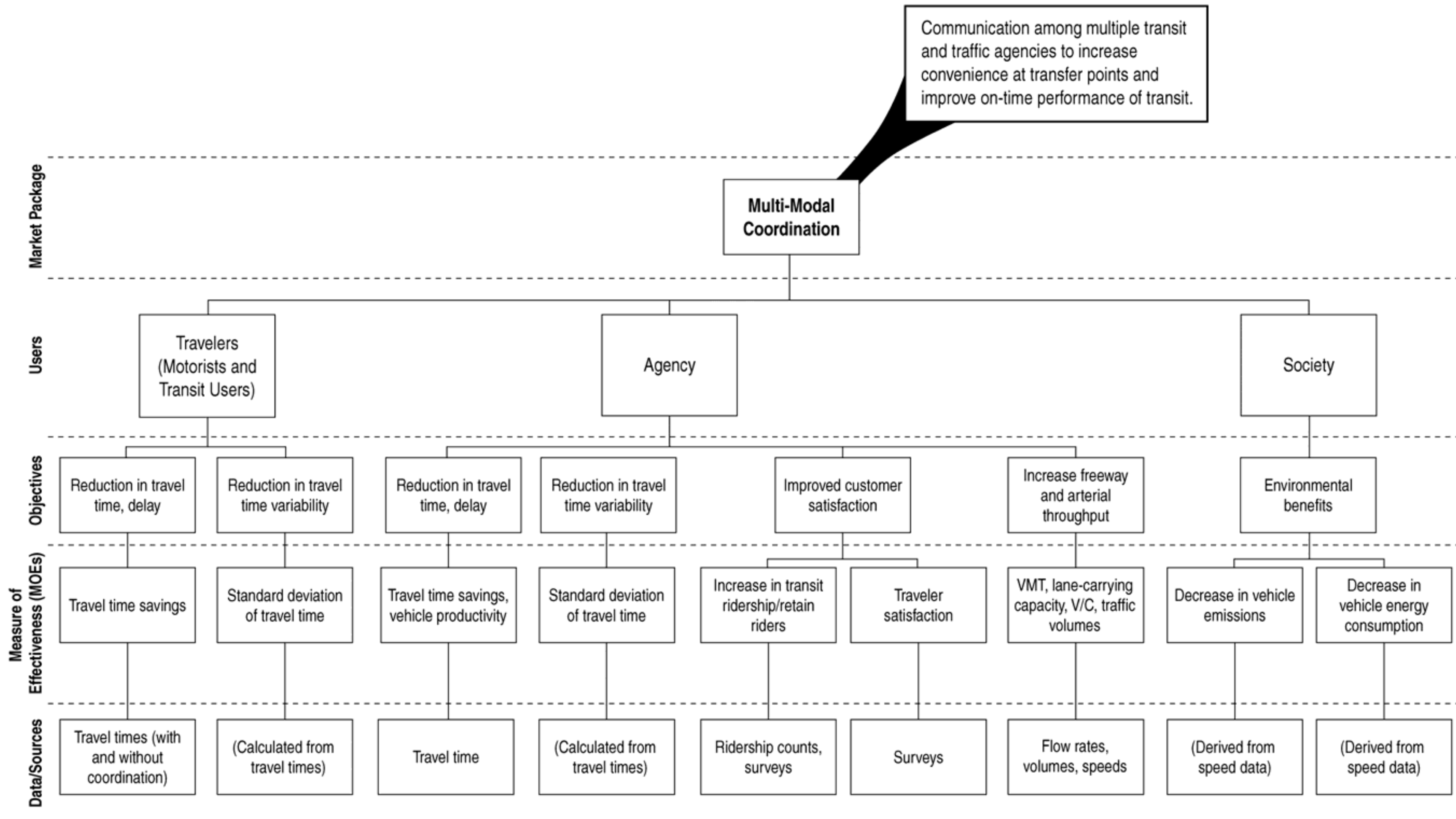

Figure A-13. APTS7 – Multi-Modal Coordination.

APTS8 – Transit Traveler Information

Description

This market package provides transit users at transit stops and on-board transit vehicles with ready access to transit information. The information services include transit stop annunciation, imminent arrival signs, and real-time transit schedule displays that are of general interest to transit users. Systems that provide custom transit trip itineraries and other tailored transit information services are also represented by this market package. (See Figure A-14.)

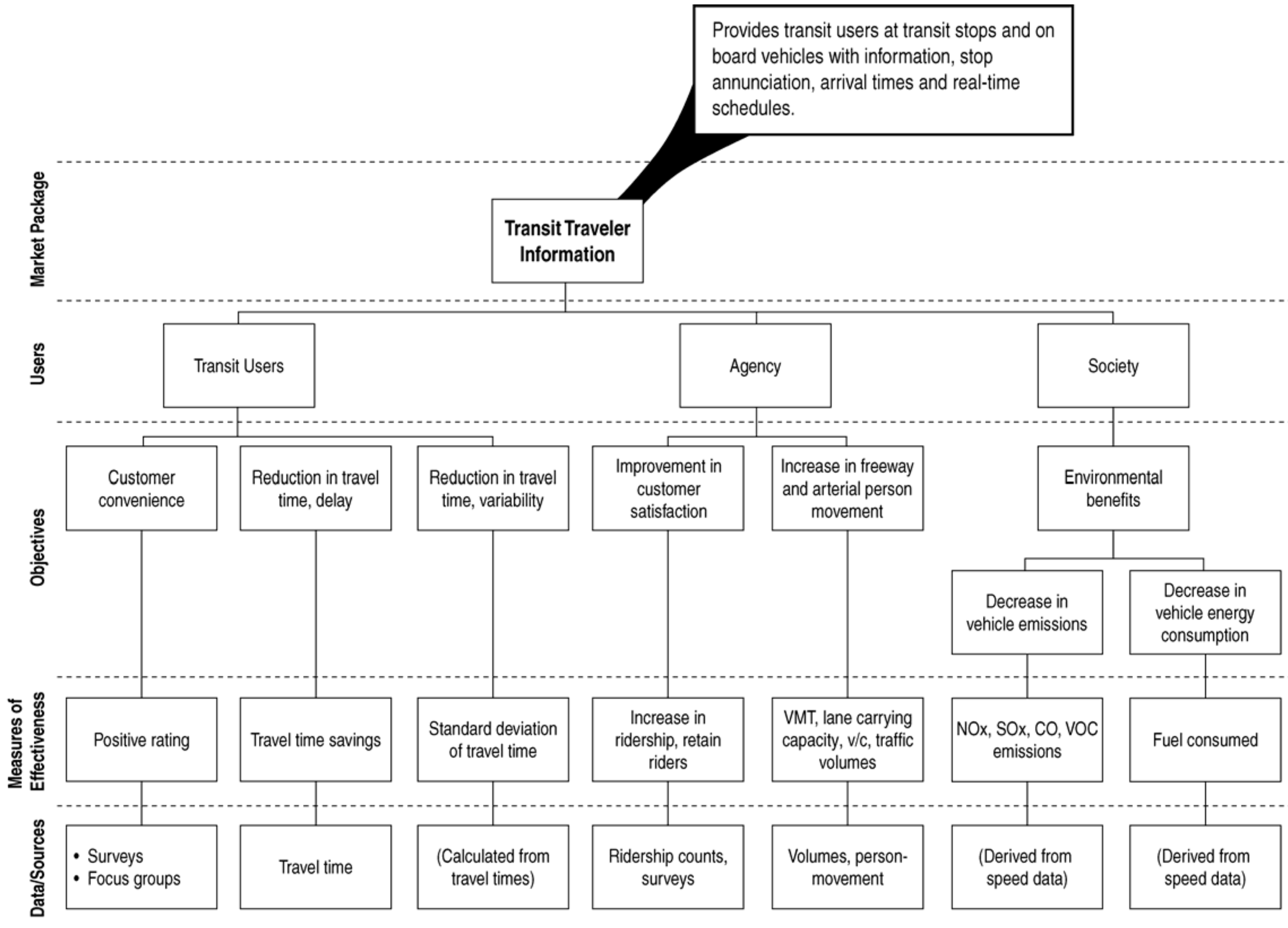

Figure A-14. APTS08 – Transit Traveler Information.

ATIS1 – Broadcast Traveler Information

Description

This market package collects traffic conditions, advisories, general public transportation, toll and parking information, incident information, air quality (AQ), and weather information, and it broadly disseminates this information through existing infrastructures and low-cost user equipment (e.g., FM subcarrier, cellular data broadcast). The information may be provided directly to travelers or provided to merchants and other traveler service providers so that they can better inform their customers of travel conditions. Successful deployment of this market package relies on availability of real-time traveler information from roadway instrumentation, probe vehicles, or other sources. (See Figure A-15.)

Analytical Commentary

This market package has a wide range of benefits serving a number of different customer groups. The evaluator should refer to the appropriate ITS study area in Appendices B through F for guidance based on selected objective(s).

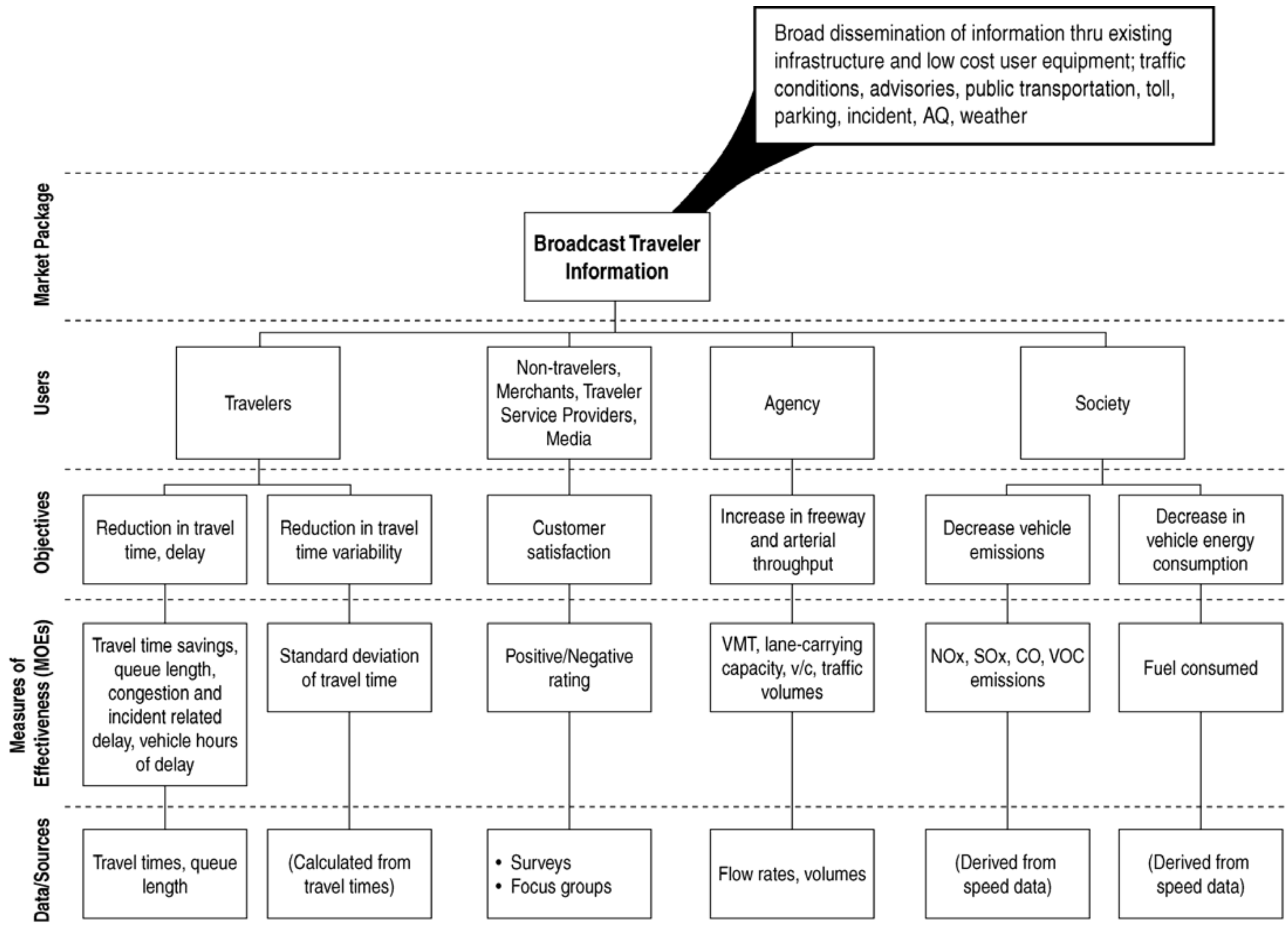

Figure A-15. ATIS1 – Broadcast Traveler Information.

CVO03 – Electronic Clearance

Description

This package provides for automated clearance at roadside check facilities. It retrieves critical information from the Commercial Vehicle Administration system using transponders and dedicated short-range communications, allowing “good” driver/vehicle/carrier to pass roadside facilities at highway speed. The facility communicates with the Commercial Vehicle Administration subsystem. The roadside check facility may be equipped with automated vehicle identification, weighing sensors, read/write transponders, and computer workstations. These data are used to sort passing vehicles and clear them through at highway speeds. (See Figure A-16.)

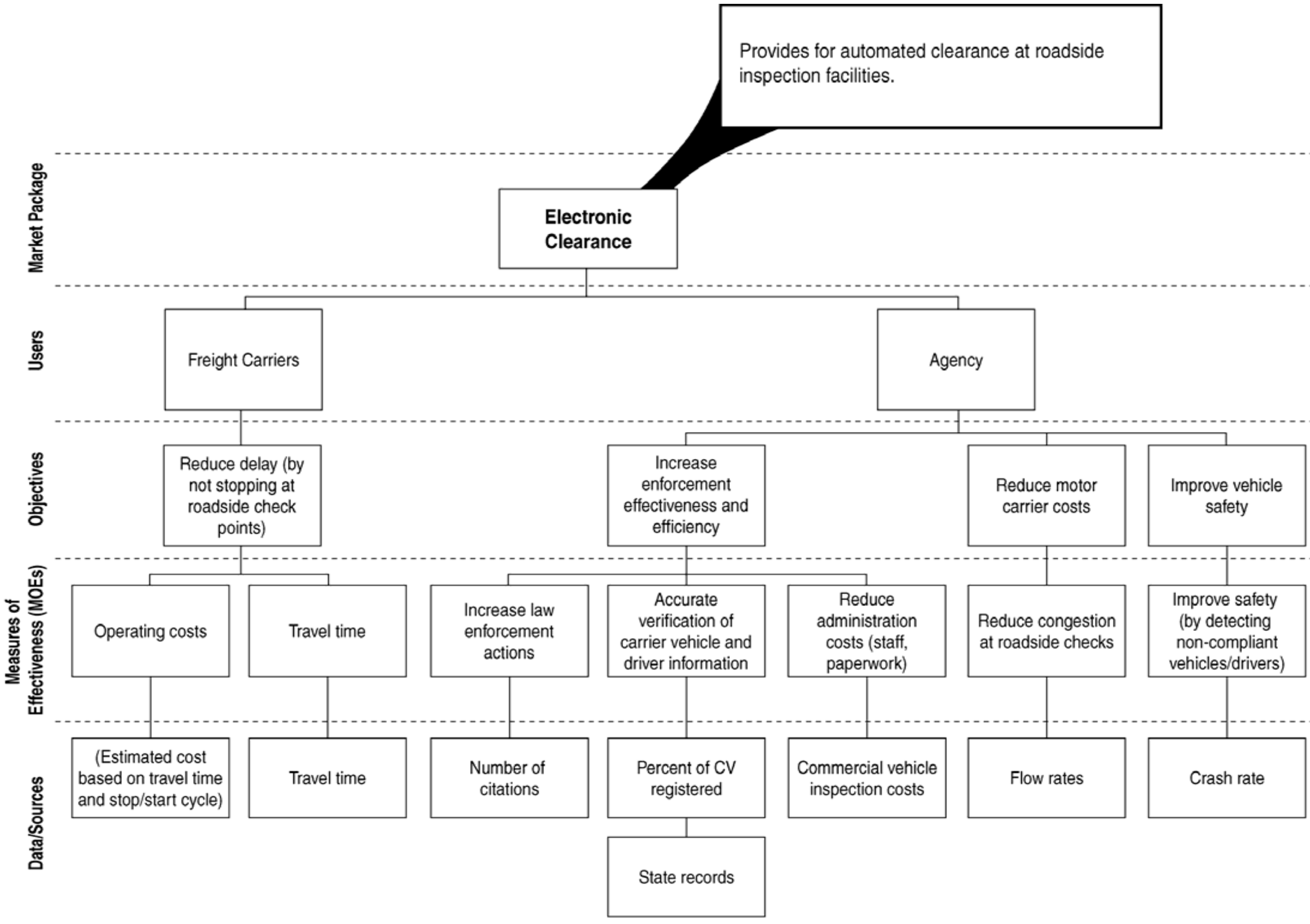

Figure A-16. CVO03 – Electronic Clearance.

CVO04 – Administrative Processes

Description

This market package provides for electronic application, processing, fee collection, issuance, and distribution of CVO credential and tax filing. Through this process, carriers, drivers, and vehicles may be enrolled in the electronic clearance program provided by a separate market package that allows commercial vehicles to be screened at mainline speeds at roadside check facilities. Through this enrollment process, current profile databases are maintained in the Commercial Vehicle Administration subsystem and snapshots of this database are made available to the roadside check facilities to support the electronic clearance process. (See Figure A-17.)

Analytical Commentary

Benefits of this market package accrue primarily to the agency. The evaluator should refer to the institutional benefits study area (Appendix F) for guidance.

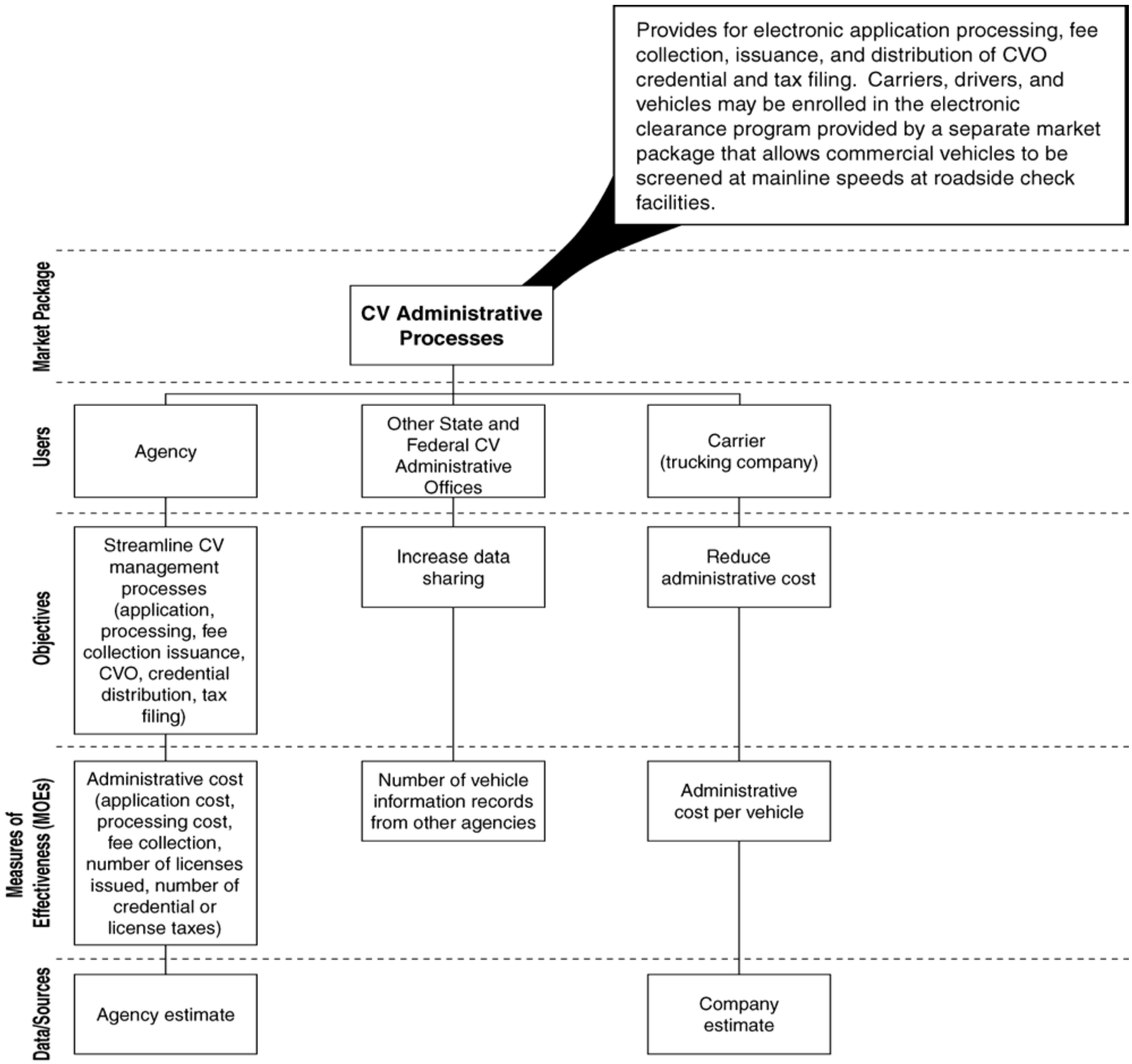

Figure A-17. CVO04 – Administrative Processes.

CVO05 – International Border Electronic Clearance

Description

This package augments the electronic clearance (CVO03) market package by allowing interface with customs-related functions providing clearance at international border crossings.
(See Figure A-18.)

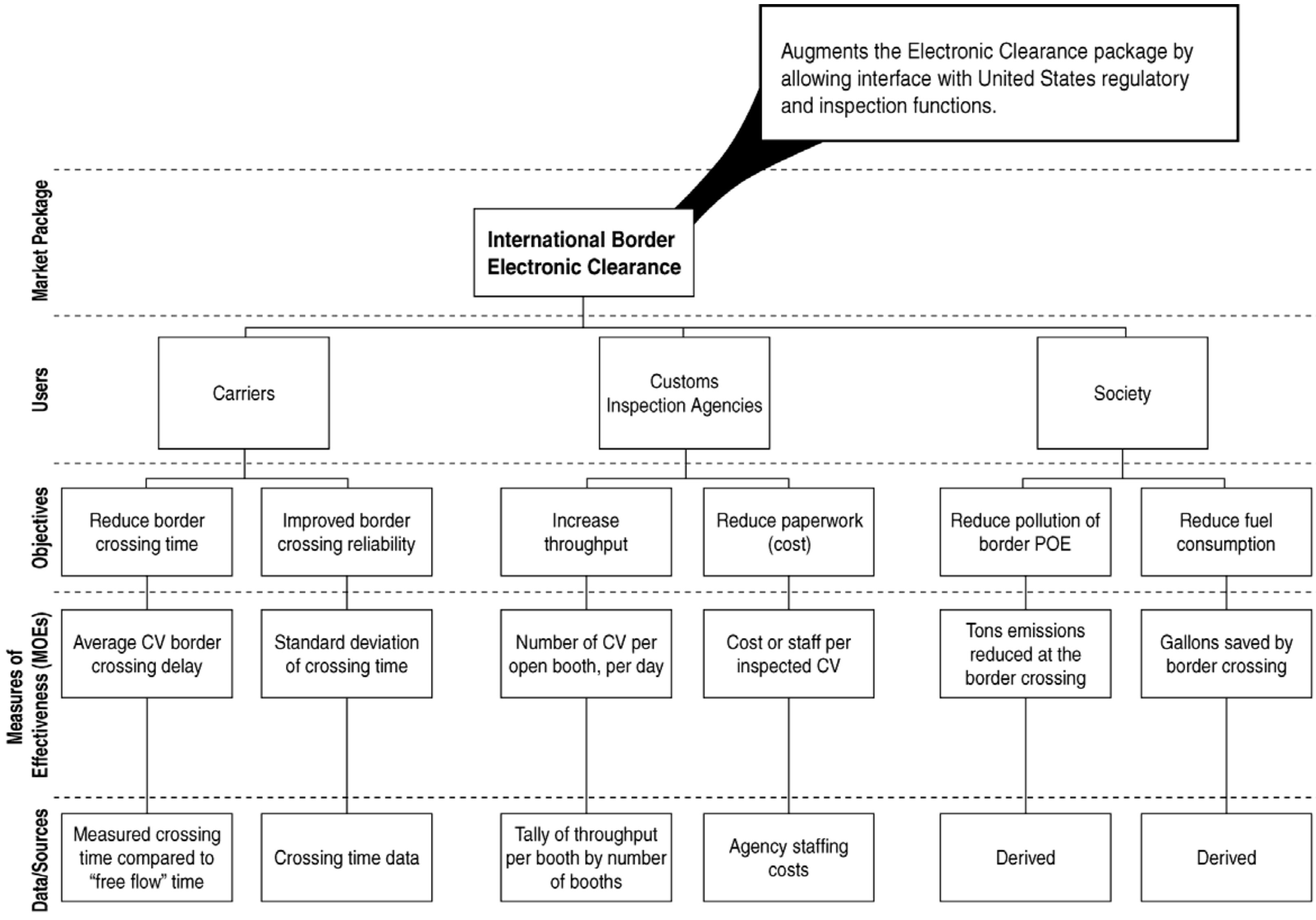

Figure A-18. CVO05 – International Border Electronic Clearance.

CVO06 – Weigh-in-Motion

Description

This package provides high-speed WIM with or without AVI capabilities. It provides the roadside equipment that could be used as a stand-alone system or with the electronic clearance package (CVO03). (See Figure A-19.)

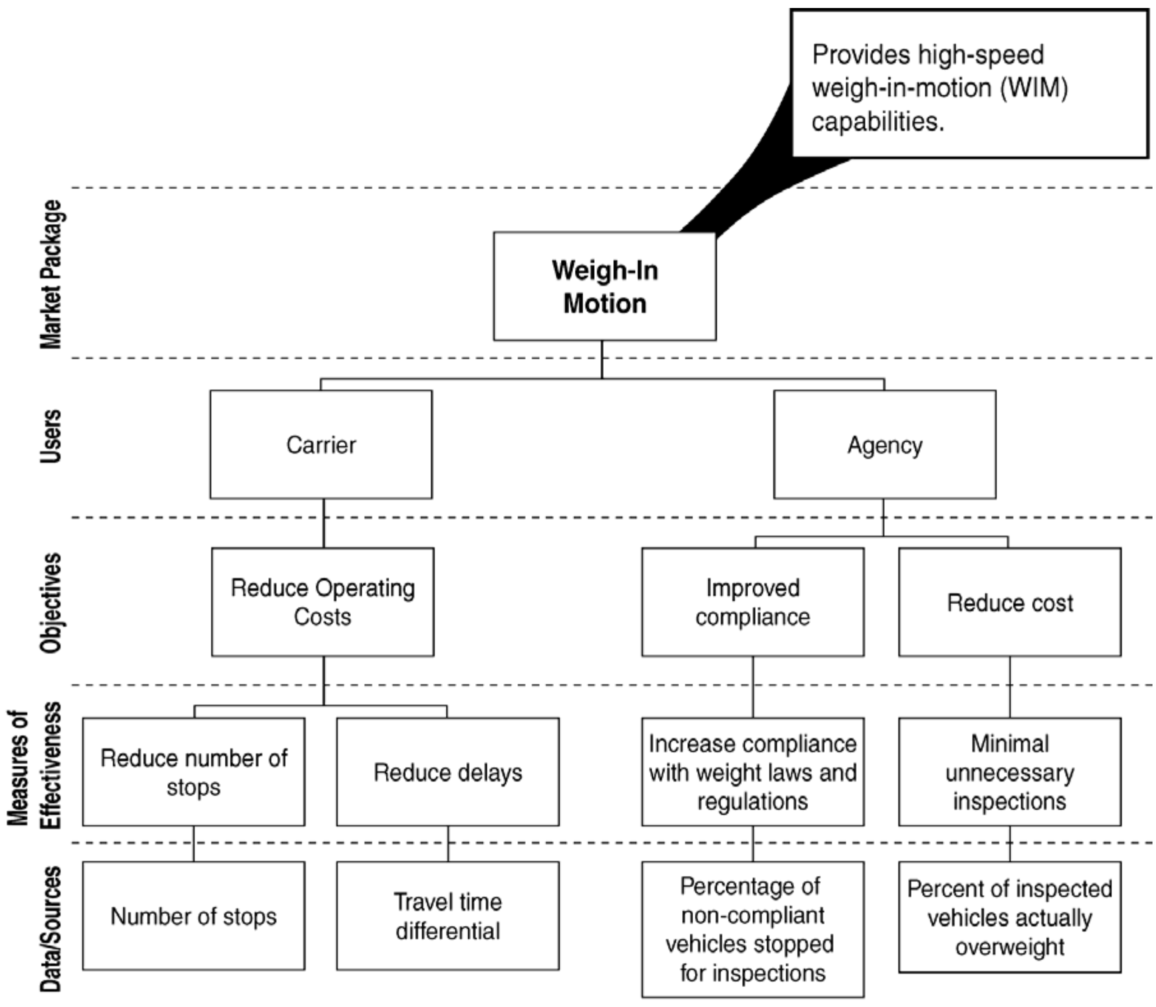

Figure A-19. CVO06 – Weigh-in-Motion.

CVO07 – Roadside CVO Safety

Description

This market package automates commercial vehicle safety inspections at the roadside check facilities. The basic option, directly supported by this market package, facilitates safety inspection of vehicles that have been pulled in, perhaps as a result of the automated screening process provided by the electronic clearance market package. Only basic identification data and status information are read from the electronic tag on the commercial vehicle.
(See Figure A-20.)

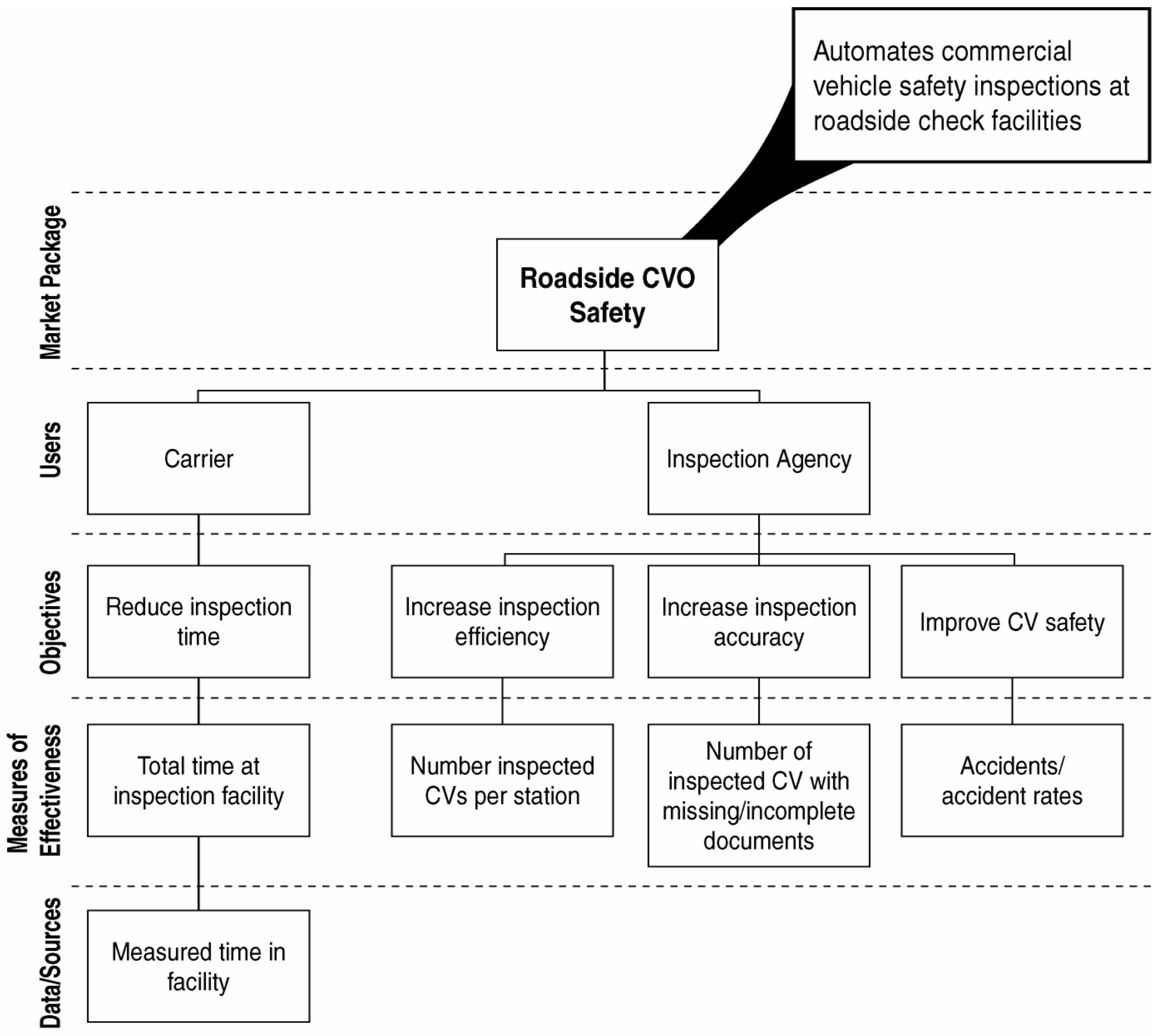

Figure A-20. CVO07 – Roadside CVO Safety.

EM1 – Emergency Response

Description

This market package includes emergency vehicle equipment used to receive and route emergency calls, and wireless communications that enable safe and rapid deployment of appropriate resources to an emergency. Coordination between emergency management subsystems supports emergency notification and coordinated response between agencies. (See Figure A-21.)

Analytical Commentary

Benefits of this market package accrue primarily to the agency. Emergency response supports other market packages (e.g., incident management, emergency routing, mayday support, and roadway service patrols). The evaluator should refer to the institutional benefits study area (Appendix F) for guidance.

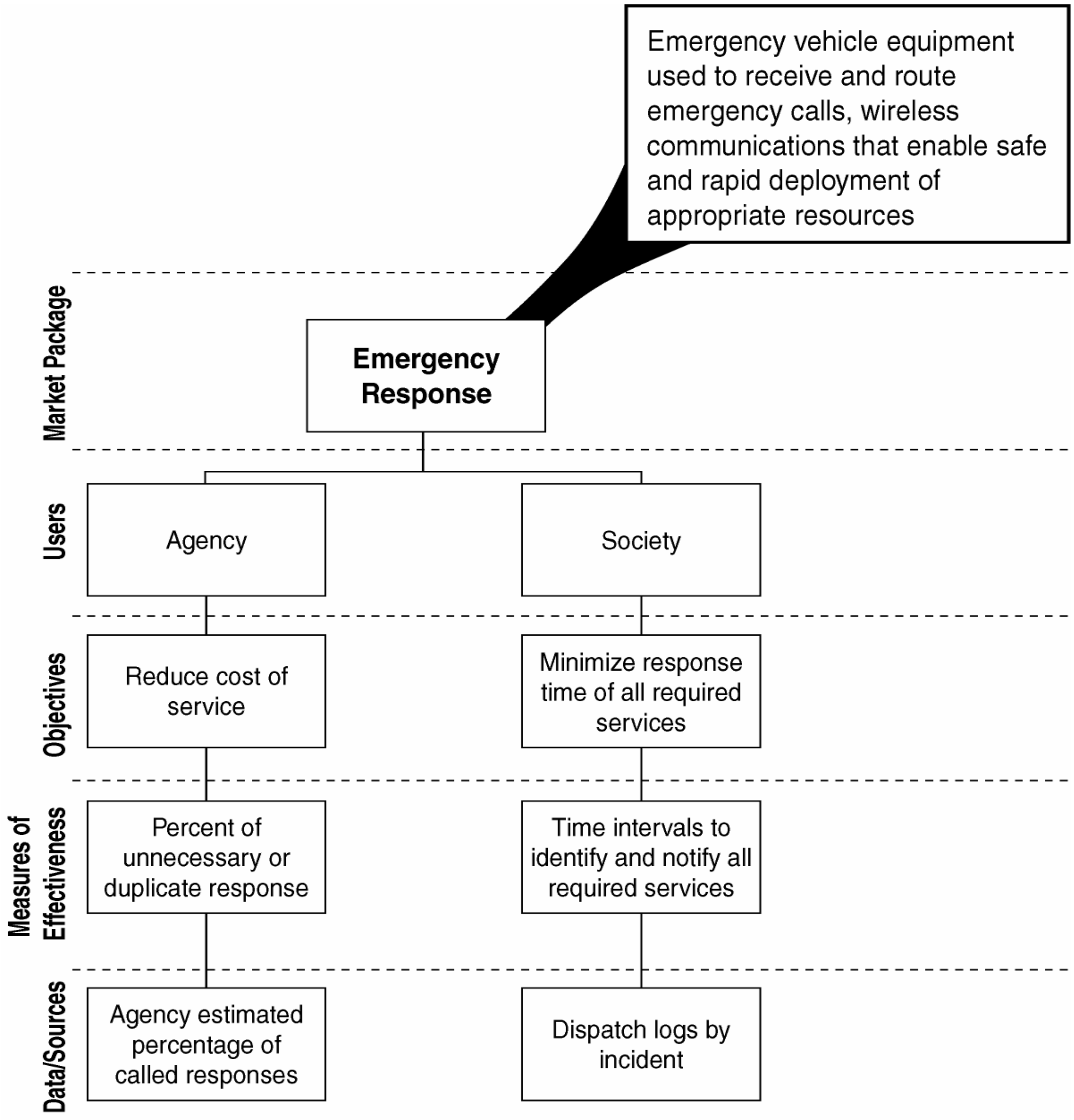

Figure A-21. EM1 – Emergency Response.

EM2 – Emergency Routing

Description

This market package supports automated vehicle location and dynamic routing of emergency vehicles. The service also supports coordination with the traffic management subsystem, collecting detailed road network conditions and requesting special priority or other specific emergency traffic control strategies on the selected route(s). The emergency management subsystem provides the routing for the emergency fleet based on real-time traffic conditions. The emergency vehicle may also be equipped with dedicated short-range communications for local signal preemption. The service provides for information exchange between care facilities and both the emergency management subsystem and emergency vehicles. (See Figure A-22.)

Analytical Commentary

This market package has a wide range of benefits serving a number of different customer groups. The evaluator should refer to the appropriate ITS study area in Appendices B through F for guidance based on selected objective(s).

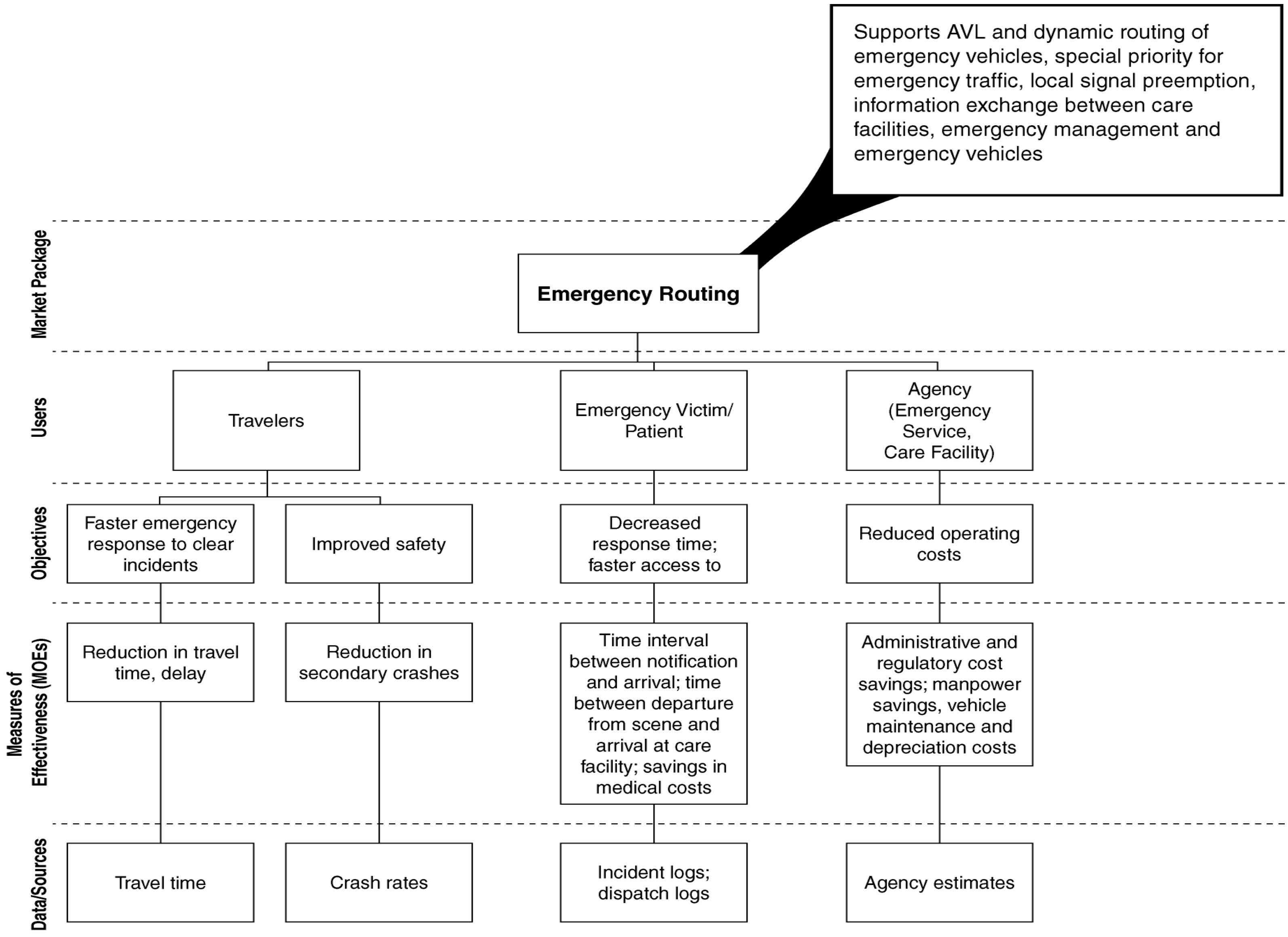

Figure A-22. EM2 – Emergency Routing.

EM4 – Roadway Service Patrols

Description

This package supports service patrol vehicles that monitor roads to offer rapid response to minor incidents or to provide assistance to the motorist. (See Figure A-23.)

Analytical Commentary

A Southwest Region University Transportation Center (SWUTC) graduate student paper titled "Analysis of Freeway Service Patrol Organization and Operation" summarizes the information gathered from a survey of 19 agencies across the U.S. that are utilizing freeway service patrol (*23*). The paper describes both organizational and operational characteristics of the FSP programs operated at these locations. Some operational characteristics of FSPs are summarized in Table A-13 (*23*).

Table A-13. Freeway Service Patrol
Number of Miles Patrolled vs. Number of Vehicle Comparisons.

Freeway Service Patrol Name	City	Miles *	# of Vehicles**	# During Peak Hour	Peak Hour Veh/ Mile
Highway Emergency Local Patrol	Albany, NY	35	3	2	0.057
Freeway Service Patrol	Carson City, NV	30[a]	6	3	0.100
Incident Management Assistance Patrol	Charlotte, NC	55	8	3[b]	0.073
Emergency Service Patrol	Cherry Hill, NJ	44	10	6	0.136
Emergency Traffic Patrol	Chicago, IL	80[a]	35	10[b]	0.125
ARTIMIS/CVS Samaritan	Cincinnati, OH	88	5	5	0.057
Mile High Courtesy Patrol	Denver, CO	45	12	12	0.267
Motorist Assistance Program	Houston, TX	190[a]	18	7[b]	0.037
Service Patrol	Kansas City, KS	1000[a]	4	4	0.004
Metro Freeway Service Patrol	Los Angeles, CA	411[a]	146	146	0.355
Hoosier Helpers	Louisville, KY	40	2	2	0.050
Freeway Friends	Louisville, KY	40	2	2	0.050
CHART Emergency Traffic Patrol	Maryland (state wide)	405[a]	N/A	18[d]	0.044
Milwaukee County Enhanced Freeway Patrol	Milwaukee, WI	60	4[a]	4[a]	0.067
Highway Helper Program	Minneapolis, MN	170	9	8	0.047
Tennessee HELP	Nashville, Memphis, Chattanooga, Knoxville, TN	120[c]	36[c]	14[c]	0.044
Bay Area Freeway Service Patrol	Oakland, CA	362	57	57	0.157
Metro Freeway Service Patrol	Sacramento, CA	90	17	17	0.189
Courtesy Patrol	San Antonio, TX	120	6	2	0.017
Motorist Assistance	St. Louis, MO	131	14	14	0.107
Freeway Incident Response Team	Virginia Beach, VA	100[a]	24	10	0.100

* Miles reported is centerline miles reported in survey unless noted.
** Number of freeway service patrol vehicles (not including supervisor or special equipment).

a. Estimated.
b. Variable number of vehicles used during peak hour, minimum value is reported in table.
c. Four cities combined.
d. Nine vehicles in Washington DC area, eight in Baltimore area, and one in Frederick area.

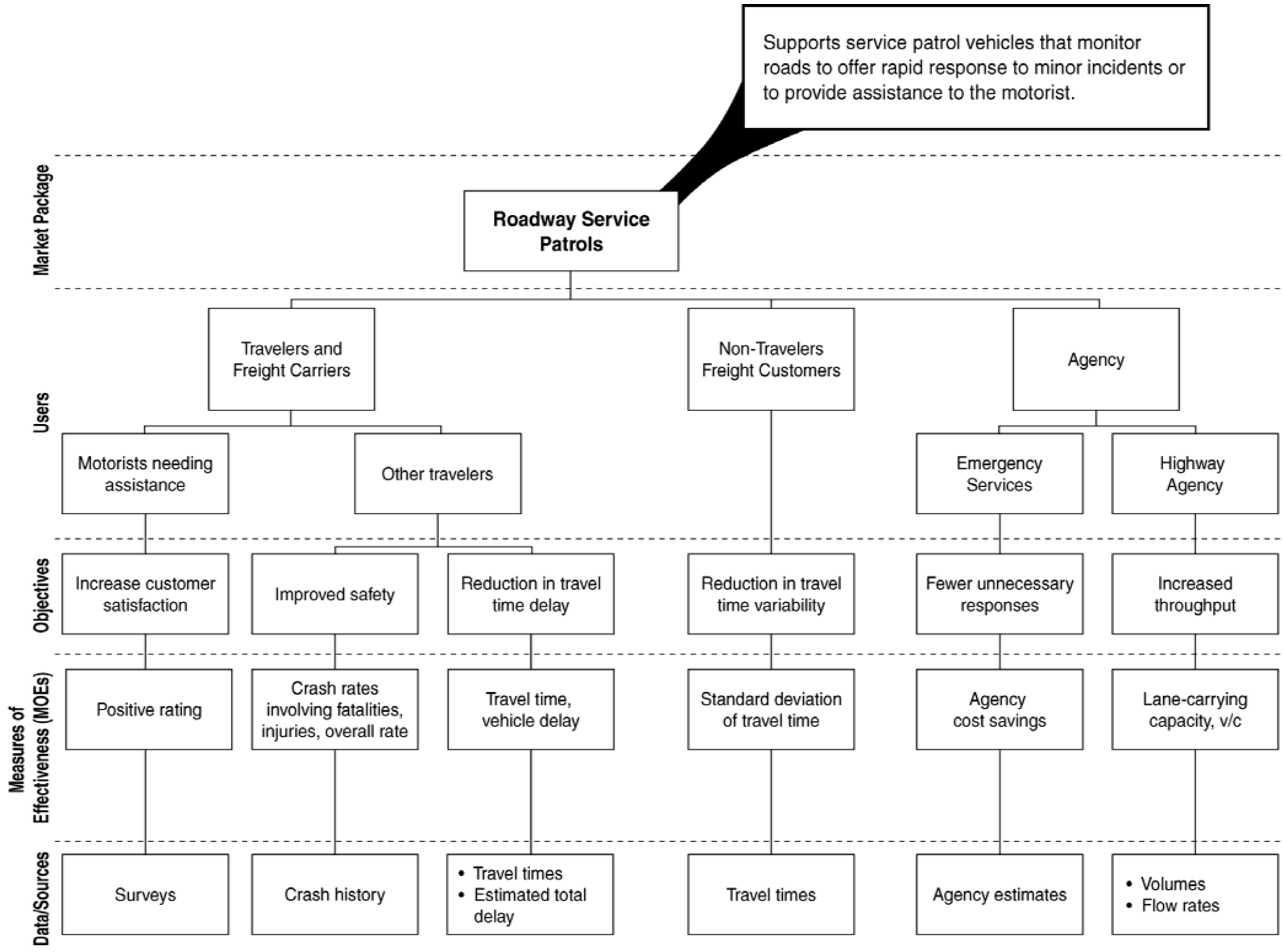

Figure A-23. EM4 – Roadway Service Patrols.

AD1 – ITS Data Mart

Description

This market package provides a focused archive that houses data collected and owned by a single agency, district, private-sector provider, research institution, or other organization. This focused archive typically includes data covering a single transportation mode and one jurisdiction that are collected from an operational data store and archived for future use. It provides the basic data quality, data privacy, and meta data management common to all ITS archives and provides general query and report access to archive data users. (See Figure A-24.)

AD2 – ITS Data Warehouse

Description

This market package includes all the data collection and management capabilities provided by the ITS data mart, and it adds the functionality and interface definitions that allow collection of data from multiple agencies and data sources spanning across modal and jurisdictional boundaries. It performs the additional transformations and provides the additional meta data management features that are necessary so that all these data can be managed in a single repository with consistent formats. The potential for large volumes of varied data suggests additional on-line analysis and data mining features that are also included in this market package, in addition to the basic query and reporting user access features offered by the ITS data mart.

AD3 – ITS Virtual Data Warehouse

Description

This market package provides the same broad access to multimodal, multidimensional data from varied data sources as in the ITS data warehouse market package, but it provides this access using enhanced interoperability between physically distributed ITS archives that are each locally managed. Requests for data that are satisfied by access to a single repository in the ITS data warehouse market package are parsed by the local archive and dynamically translated to requests to remote archives that relay the data necessary to satisfy the request.

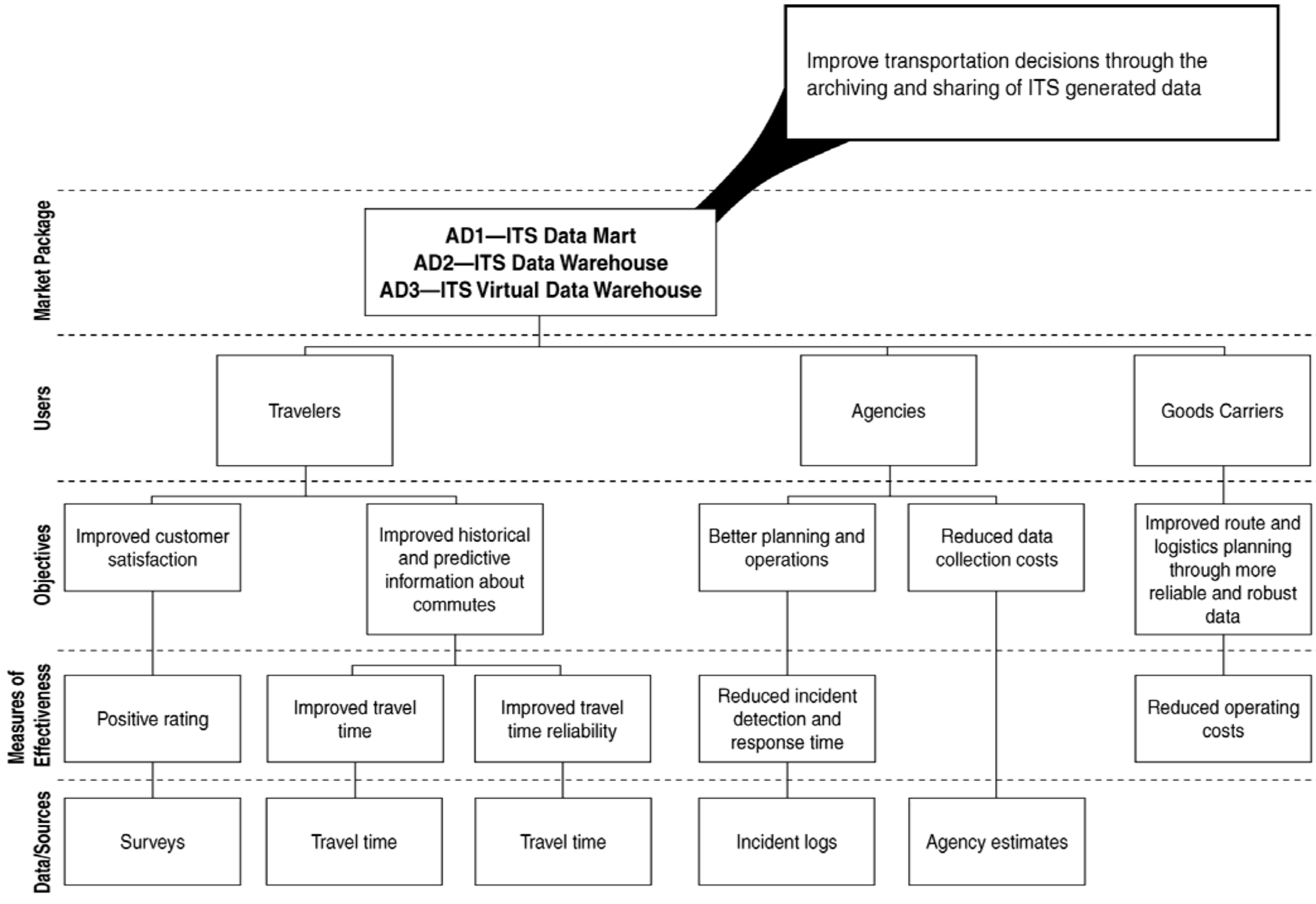

Figure A-24. AD1, AD2, AD3 – ITS Data.

MC03 – Road Weather Data Collection

Description

This package collects current road and weather conditions using data collected by environmental sensors on or around the roadway. The collected data are used by the weather information processing and distribution market package to process the information and make operational decisions based on the information. (See Figure A-25.)

Analytical Commentary

Benefits of this market package accrue primarily to the agency. Road weather data collection supports the weather information processing and distribution market package and, on its own, improves the reliability of monitoring, detecting, or collecting weather-related data. The evaluator should refer to the institutional benefits study area (Appendix F) for guidance.

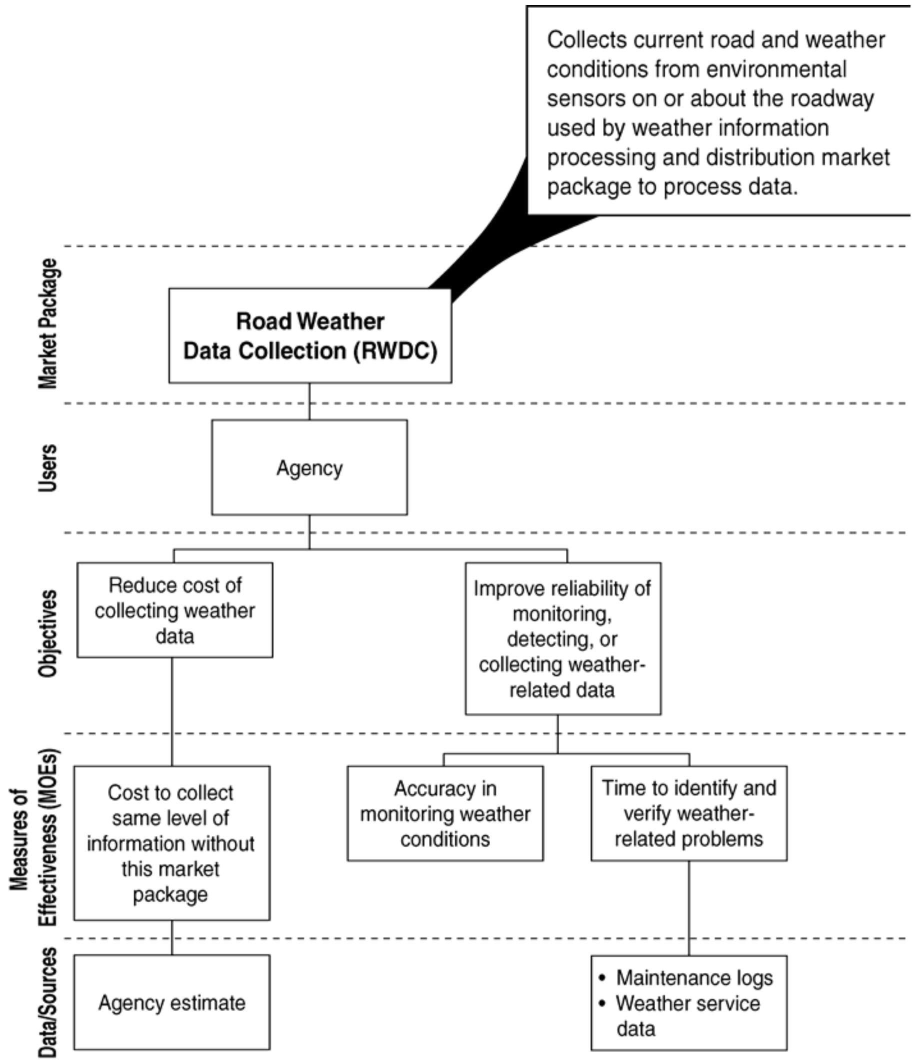

Figure A-25. MC03 – Road Weather Data Collection.

MC04 – Weather Information Processing and Distribution

Description

This package processes the information and data collected from the road weather data collection market package. The data are used to detect environmental hazards such as icy conditions, high winds, or dense fog. Continuously updated information may be used to more effectively deploy maintenance crews, as well as provide advisories to motorists. (See Figure A-26.)

Analytical Commentary

This market package has a range of benefits serving several different customer groups. The evaluator should refer to the appropriate ITS study area in Appendices B through F for guidance based on selected objectives.

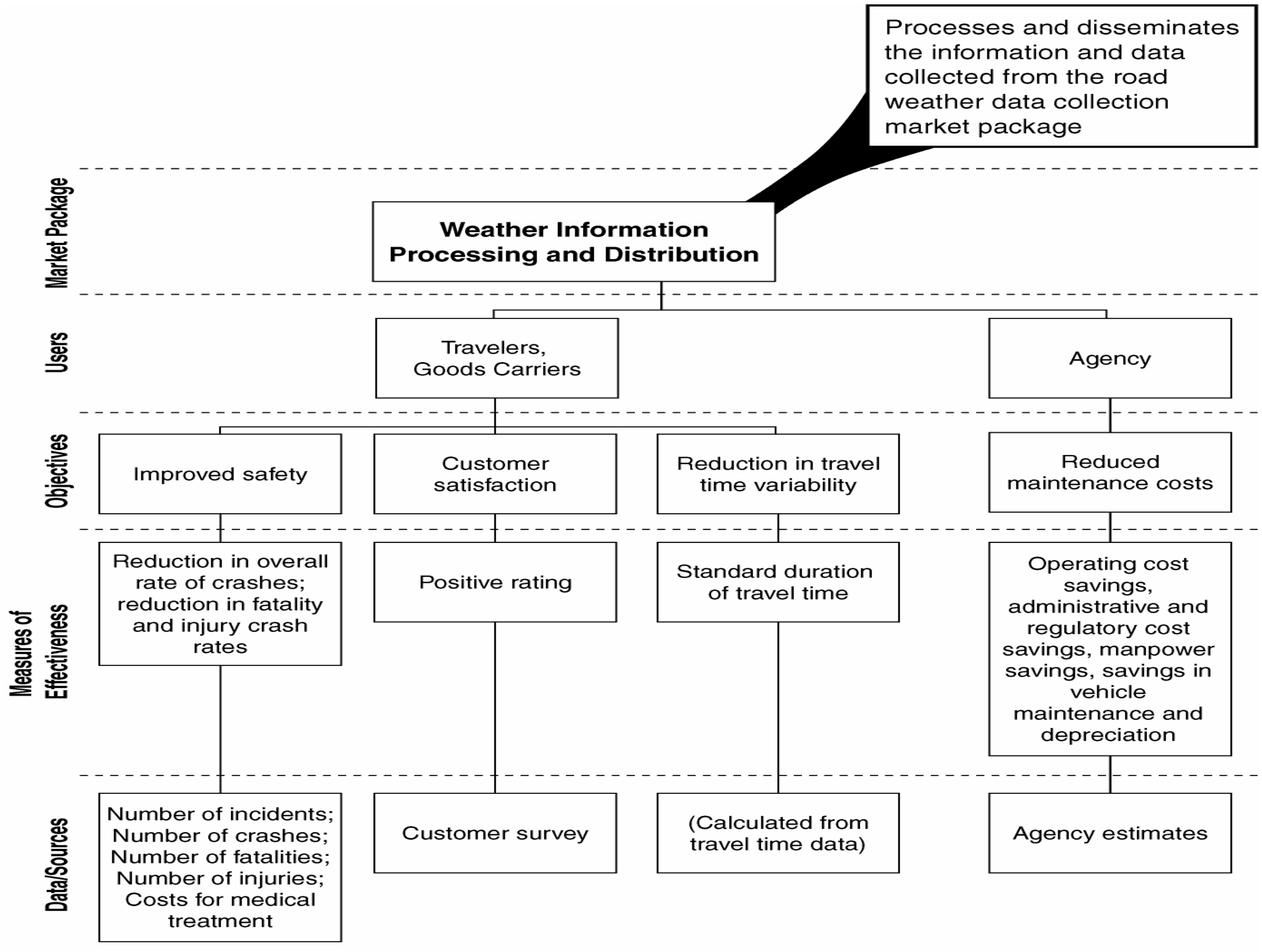

Figure A-26. MC04 –Weather Information Processing and Distribution.

MC08 – Work Zone Management

Description

This package directs activity in the work zones. Dynamic message signs are used to control the traffic. Information is also related to other groups such as traffic management centers, Internet service providers, and other maintenance and construction centers for better coordination. Information about speeds and delays are provided to motorists prior to the work zones. (See Figure A-27.)

Analytical Commentary

This market package has a wide range of benefits serving a number of different customer groups. The evaluator should refer to the appropriate ITS study area in Appendices B through F for guidance based on the selected objectives.

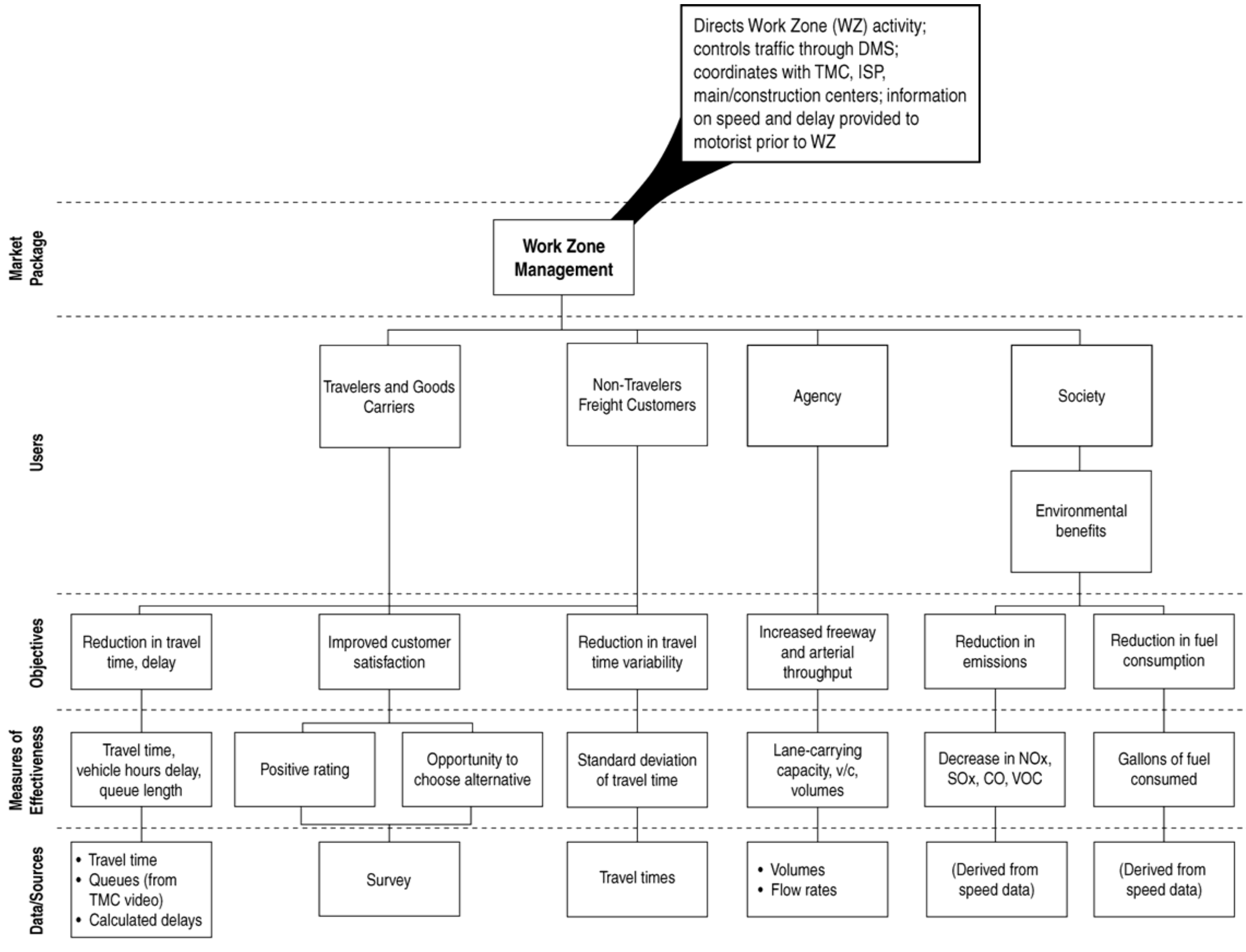

Figure A-27. MC08 – Work Zone Management.

APPENDIX B. ITS STUDY AREA: OPERATIONAL EFFICIENCY EVALUATION

GOALS AND MOES

The purpose of an operational efficiency study is to estimate the impacts that an ITS component or market package has on a transportation system's mobility and efficiency. *Mobility* is expressed quantitatively through MOEs such as travel time delay and travel time variability. From the perspective of individual users of a system, delay is usually estimated in seconds or minutes per vehicle. Day-to-day variability in overall travel time from a particular origin to a destination in a transportation network is undesirable. Reduction of travel time variability improves the ability of individual citizens and commercial enterprises to plan and schedule their tasks. By considering ITS deployments under various incident versus non-incident scenarios and various travel demand scenarios, travel time variability throughout the course of a year can be evaluated.

Efficiency is expressed by MOEs such as throughput or effective capacity. *Effective capacity* is the maximum potential rate at which persons or vehicles may traverse a link, node, or network under a representative composite of roadway conditions. *Capacity* (as defined by the *Highway Capacity Manual*) is: "maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a given point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions." The major difference between effective capacity and capacity, as defined by the HCM, is that capacity is assumed to be measured under good weather and pavement conditions and without incidents, whereas effective capacity can vary depending on these conditions and the use of management and operations strategies such as ITS.

Throughput is defined as the number of persons, vehicles, or units of freight actually traversing a roadway section or network per unit time. Increases in throughput are sometimes realizations of increases in effective capacity. Under certain conditions, measured throughput may reflect the maximum number of vehicles that can be processed by a transportation system. Capacity (and effective capacity) is calculated given the design and operation of the network segment and does not change unless the physical construction or operations of that network segment are changed. In contrast, throughput is an observable measure and, thus, is an MOE for the efficiency ITS goal area. Care must be given to interpreting results, however, because throughput changes may be due to factors besides effective capacity changes (e.g., changes in demand). Thus, not all throughput changes are indicative of improvements in the efficiency of a given situation (*24*).

There are several levels of effort that can roughly be identified for the purpose of estimating the operational efficiency impacts for a pre-deployment study or a post-deployment implementation of ITS infrastructure. The following discussion attempts to outline several approaches to evaluating ITS components or market packages from an operational efficiency perspective.

Level 1 – Literature Review

This evaluation method involves conducting a literature review to ascertain ranges of both predicted (through modeling) and measured mobility and efficiency impacts of various ITS components.

TxDOT ITS Benefits Website

The Texas Department of Transportation, in conjunction with the Texas Transportation Institute at Texas A&M University, maintains an ITS database and website to provide TxDOT with information about programs, projects, and publications that demonstrate the benefits of ITS. The website can be accessed at: http://tti.tamu.edu/austin/its/. The goals of the database are to:

- provide TxDOT with guidance on how to compare projects, both ITS and non-ITS, for purposes of establishing deployment priorities; and
- assist TxDOT in identifying the type of ITS elements that could or should be incorporated on a standing basis into larger scale planning, such as freeway reconstruction.

The site can be browsed from several perspectives.

USDOT ITS Benefits Database

The U.S. Department of Transportation's ITS Joint Program Office (JPO) has been actively collecting information regarding the impact of ITS projects on the surface transportation network since December of 1994 (*25*). The JPO has sponsored the development of the national ITS benefits database, which is updated quarterly and is available to the public at: http://www.benefitcost.its.dot.gov/its/benecost.nsf/ByLink/BenefitsHome.

The ITS benefits data can be accessed from several perspectives at this website. Literature searches in TRIS, NTIS, and PATH for general subjects such as "intelligent transportation systems" or "measures of effectiveness" or for more specific subjects such as "ramp metering" can yield additional references possibly not found in the JPO ITS benefits database.

Level 2 – Empirical and Analytical Models

The next level of ITS evaluation involves utilizing empirical and analytical models such as those employed by the *Highway Capacity Manual*. "HCM methodologies tend to focus on individual network elements: specific facilities or collections of facilities. Their intent is to assess the level of service (LOS) provided by a particular facility with a given configuration and operational plan in response to traffic flows being accommodated…The HCM methods represent traffic flows with variables that reflect the flow dynamics. These methods stop short of representing individual vehicles. The intent is to employ calculations that can be done by hand, using a set of worksheets, or by computer, using a series of spreadsheets…"

The applications of these models are limited in various ways, such as the inability to assess shockwaves or queues that extend beyond the physical or time slice limits of a particular weaving section being studied. These models are not designed to cover large geographic areas that planning models do, nor are they designed to model the level of detail of microscopic simulation models.

The Highway Capacity Software (HCS) incorporates the analytical techniques of the HCM in several distinct modules for Basic Freeway Segments, Freeway Weaving, Ramps and Ramp Junctions, Multilane Highways, Two-Lane Highways, Signalized Intersections, Un-signalized Intersections, Urban Streets, and Freeway Facilities (multiple segments).

The first step is to define the transportation supply and demand scenario(s) as outlined in Figure B-2928 and Figure D-3029 that are to be assessed under "with ITS" and "without ITS" situations. For example, under a particular supply/demand scenario there is an incident that blocks a lane for 30 minutes on a freeway and the travel demand is at a seasonally high level and a weekday PM peak hour or peak period is being assessed. Mode split is: 99 percent person trips are in an SOV and 1 percent are on a bus.

The next step in the analysis is to define the "with ITS" and "without ITS" situations. For example, under the particular supply/demand scenario described above no one receives any information concerning this incident in the "without ITS" situation and there is no trip diversion or travel demand impact. The incident duration (30 minutes) is unaffected.
In the "with ITS" situation, the lane blockage is reduced to 15 minutes, and 5 percent of network trips delay their trip by 15 minutes because of information they received about the incident. Another 5 percent divert to the frontage roads around the incident. Estimates of these types of ITS changes to transportation supply characteristics (e.g., link capacity or effective capacity, signal timing plans) and travel demand (e.g., trip generation, mode shift, temporal shift) are made via the ITS literature.

These supply and demand modifications are then input into the appropriate HCS module(s), and the model then estimates the operational efficiency impacts. In this manner, the analyst will be able to assess "with ITS" and "without ITS" scenarios for year one through whatever future year the analysis will be conducted. If estimations of total daily (peak and off-peak) and annual impacts are desired, the analysis will require defining multiple supply/demand scenarios and assigning percentages to these scenarios that reflect their frequency throughout a given year.

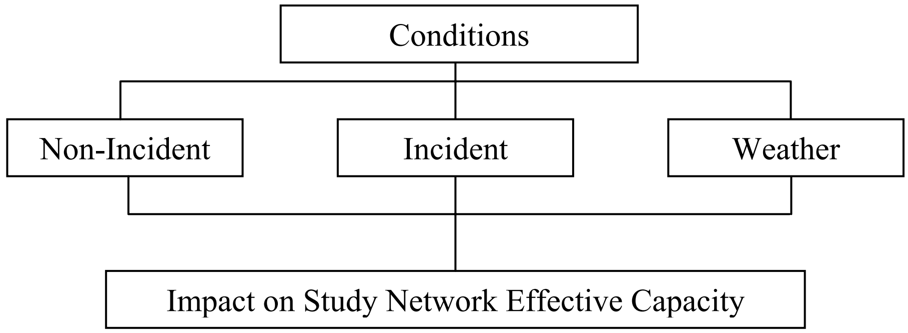

Figure B-28. Transportation Supply Infrastructure Conditions.

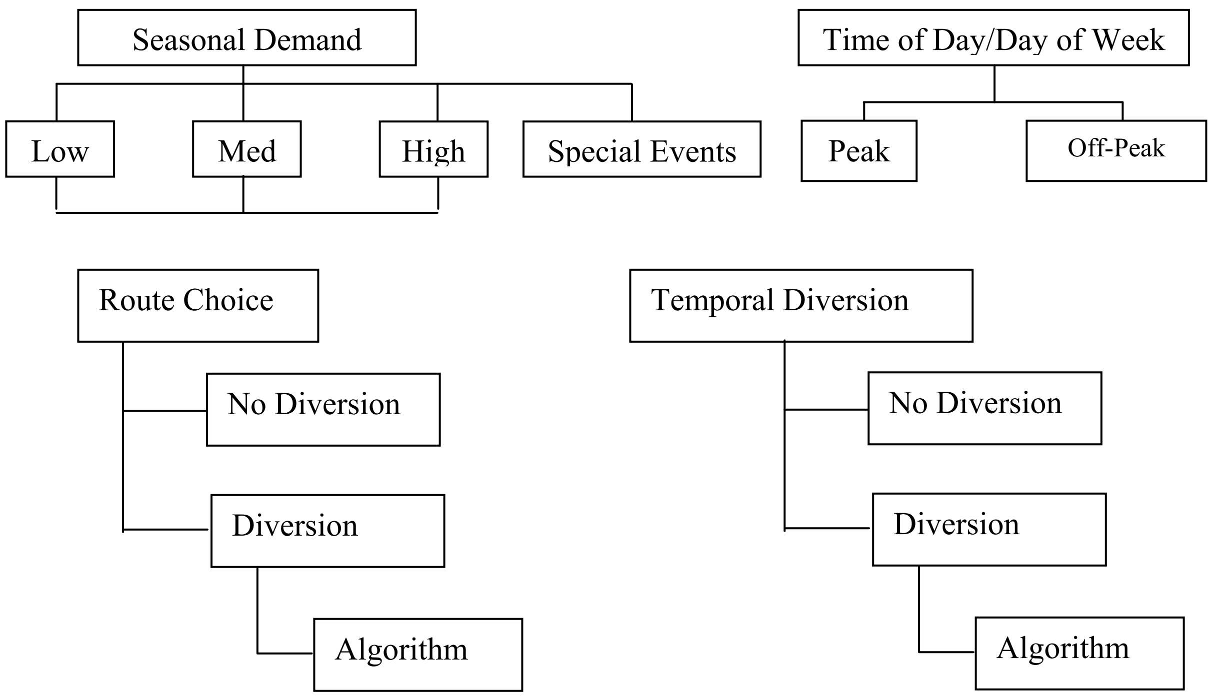

Figure B-29. Travel Demand Conditions.

Level 3 – Sketch Planning Spreadsheets

Sketch planning spreadsheets include:

- SCRITS (designed as an ITS evaluation spreadsheet),
- SPASM (general sketch planning tool that can be adopted for ITS evaluation),

- STEAM (general sketch planning tool that can be adopted for ITS evaluation), and
- Cambridge Systematics, Inc. Sketch Methods for Estimating Incident-Related Impacts (based on QSIM).

As in the Level 2 analysis, the first step is to define the transportation supply and demand scenario(s) as outlined in Figure B-298 and Figure D-3029 that are to be assessed under "with ITS" and "without ITS" situations. For illustrative purposes, a different example than given in the Level 2 analysis discussion is presented. Under a particular supply/demand scenario there are special events in an area that occur on weekends 50 percent of the year (26 weekends per year). The "background" travel demand is at a seasonally medium level, and the special event increases this demand level by 30 percent. Mode split is: 100 percent "background" person trips in vehicles with average occupancy of 1.1; special event person trips are 95 percent in vehicles with average occupancy of 2.0, and 5 percent in buses with average occupancy of 15.0. In the "without ITS" situation, AM radio traffic conditions broadcasts cause 10 percent of the person trips that would have taken the major freeway southbound from 51st Street to 5th Street to take a parallel arterial route. No changes are made to the signal system.

In the "with ITS" situation, ramp metering is utilized, as well as the provision of website traffic information that is accessed by most persons at home (pre-trip). This ITS deployment also includes the capability of a traffic responsive signal system. The ITS impacts on supply and demand are: an additional 10 percent of the person trips that would have taken the major freeway divert to the parallel arterial. The responsive signal timing changes increase the cycle length from 90 seconds to 120 seconds with all of the additional 30 seconds of green being allocated to the north/south direction.

Level 4 – ITS Evaluation Package with Planning Model

ITS Deployment Analysis System (refer to Chapter 3: Tools to Aid in Estimation of Benefits)

Level 5 – Regional Planning Model/Sub-Area Simulation Model Iterative Process

Mitretek Systems has developed an ITS evaluation methodology called "Process for Regional Understanding and Evaluation of Integrated ITS Networks (PRUEVIIN)." It features a traditional four-step transportation planning model as well as a traffic simulation to capture regional and corridor level ITS impacts. For this study, EMME/2 is implemented as the transportation planning model and INTEGRATION 1.5 is implemented as the simulation model" (*26*). This evaluation method was utilized in the Metropolitan Model Deployment Initiative (MMDI) evaluation in Seattle. According to Mitretek Systems:

"The performance of each alternative is evaluated using a combination of a planning model and a simulation. The regional planning model is employed to identify impacts on travel demand including trip distribution, mode choice, and regional assignment. The regional travel demand model represents long-term adaptation by the travelers in the system to average conditions experienced in the peak period"(*26*).

Because particular types of ITS enhancements may be beneficial in very different situations, a series of 30 scenarios were analyzed. Each scenario is composed of a combination of characteristics of weather, travel demand variation, incidents, and crashes. Each scenario has a probability of occurrence and, taken together, comprise various situations of travel demand and of operational characteristics of transportation infrastructure over the course of a year. Evaluating multiple scenarios such as these facilitates estimating annual impacts as well as the estimation of travel time variability as an MOE.

The MMDI evaluation in San Antonio (*27*) was conducted by Science Applications International Corporation and employed several different methodologies including focus groups, surveys, interviews, traffic simulation, as well as analysis of traffic and usage data. Customer satisfaction studies were conducted for both the public and private sectors. Public-sector customer satisfaction was estimated through a series of one-on-one interviews with various public agencies such as TxDOT, VIA Metropolitan Transportation Authority, San Antonio Police Department, the Texas Transportation Institute, and the local media. Private-sector (citizens commuting in San Antonio) customer satisfaction was estimated through a series of three 90-minute focus groups. Two groups were recruited from the general public and one group from the "USAA panel" group, a group of "expert consumers" who work in the area at the USAA Insurance Company and who are part of an ongoing VMS study being conducted by TTI.

Evaluation of the system efficiency, safety, and fuel consumption impacts was largely conducted through micro-simulation modeling. A modeling approach allowed the individual impacts of ITS components to be evaluated, as well as the integration of those components. The micro-simulation model INTEGRATION was employed. INTEGRATION has been developed "…specifically for studying the effectiveness of alternative information supplying strategies, as well as alternative information/control system configurations, for urban traffic networks with Advanced Traveler Information Systems (ATIS) and/or Advanced Traffic Management Systems (ATMS)" (*28*).

Multiple incident scenarios were identified in the San Antonio evaluation study from a previous study of police incident logs (*29*). Modeling of multiple incident scenarios allows an estimation of ITS impacts under varying conditions and allows the results to be normalized to annual results (annual frequencies of various incident scenarios can be estimated, as well as the impact that each incident scenario has on effective capacity).

Rather than developing a new or utilizing an existing urban planning model for estimating an origin-destination trip table for the study corridor, the QUEENSOD model was used to estimate this information required by INTEGRATION. "With ITS" and "Without ITS" scenarios are modeled based on estimates of information received by drivers, driver reaction to this information, signal timing plans on surface streets, and estimates of incident durations. Individual ITS components are modeled, as well as combinations of ITS components to assess impacts of ITS component integration.

APPENDIX C. ITS STUDY AREA: SAFETY EVALUATION

GOALS AND MOES

The purpose of a safety study is to assess the impacts that a given ITS market package has on a transportation system's safety. Safety is expressed quantitatively through MOEs such as the number of crashes, crash rate, and crash severity. The total number of crashes is an important consideration due to the potential for diversion of traffic with an ITS deployment.

The crash rate is an important MOE as it "normalizes" the number of crashes based on exposure (i.e., the amount of travel on a section of roadway or through an intersection). The crash rate is normally expressed in number of crashes per million vehicle-miles traveled on a section of roadway or in number of crashes per million vehicles traveling through an intersection.

Finally, crash severity is an important consideration because it deals with the cost of crashes in terms of fatalities, injuries, and property damage. Changes in roadway or intersection geometry or operations, such as with an ITS deployment, can affect the types of crashes that occur. It is possible to observe an increase in the number of crashes or crash rate along a particular section of roadway, but the types of crashes occurring might be less severe.

Safety Study Issues

Estimating the safety impacts of an ITS market package(s) is difficult due to the fact that there are many factors involved that can potentially contribute to the causes and prevention of a crash. These factors include driver skill, driver aggressiveness, driver attention, driver fatigue, speed and speed differential between lanes, level of congestion, type and difficulty of driving maneuver (e.g., changing lanes, making a permissive left turn, etc.), lighting, weather, level of law enforcement presence, and roadway geometry and operations.

A given ITS market package might affect one or more of these factors, while other measures being taken (e.g., increase in law enforcement presence) might affect some of these factors as well. In estimating the safety impacts of an ITS market package, the analyst is attempting to control for all other potential explanatory factors involved in a crash. There are two basic methodologies for estimating the safety impacts of an ITS deployment: 1) use of a predictive statistical model, and 2) analysis of field data before and after ITS deployment. These two methodologies are described in the following sections:

Predictive Crash Models

Statistical models attempt to predict the effect a treatment (ITS treatment or other types of treatments) has on crashes by developing relationships between factors estimated to contribute to the cause of crashes and the number of crashes. Crash predictive models have often been based on multiple-linear regression, under the assumption that the number of crashes is normally distributed. The predictive power of such models has generally been disappointing (*24*). As cited by the Midwest Research Institute's study, there are several reasons why multiple-linear regression models do not predict crashes well (*24*):

- Crash rates often do not follow a normal distribution due to the random, sporadic nature of crashes.
- Crashes at a particular location are small in number and small counts typically do not follow a normal distribution.
- Crash rates and frequencies are necessarily non-negative, but traditional multiple-linear regression models are not constrained from predicting negative crash frequencies.

The study states, "Therefore, the Poisson and negative binomial distributions are often more appropriate for discrete counts of events that are likely to be zero or a small integer during a given time period" (*24*).

The first step in either choosing an existing model or developing a model is to determine what operational characteristics or factors the ITS deployment is affecting (e.g., weaving intensity, speed differentials). The second step is to make certain the model includes these factors, as well as other factors that need to be controlled, so that the effects of the ITS treatment can be isolated.

Before and After Crash Data Analysis

There are several considerations when conducting a before and after study of crash data that affect the validity of the evaluation study. These considerations are discussed in the following sections.

Regression-to-Mean-Bias

An important consideration when conducting analysis of empirical crash data before and after ITS deployment is regression-to-the-mean bias. If a study site or corridor is chosen because in the time period before ITS deployment it experiences what is considered to be a high number of crashes, the site will probably have a lower number of crashes the following time period regardless of the ITS deployment. This phenomenon is known as regression-to-the-mean bias (*30*, *31*).

"Therefore, a simple before-and-after comparison for sites where the treatment is selected based on the crash experience is likely to result in an overestimation of the treatment's effect" (*30*). In order to minimize the problem of regression-to-the-mean bias, the use of a statistical analysis method known as the Bayesian approach is utilized. The Bayesian approach makes use of the knowledge gained in the past in the form of crash history and expert judgment (*32*). The FHWA has developed a microcomputer program titled Empirical Bayes Estimation of Safety and Transportation (EBEST) that utilizes the Bayesian approach to analyze before-and-after crash data (*30*). The EBEST method utilizes crash data from study reference sites that are similar to the site being treated with ITS technologies but are not affected by the ITS deployment.

Controlling for Other Explanatory Factors

Another important consideration when conducting analyses of empirical crash data before and after ITS deployment is controlling for other explanatory parameters that might be contributing to the change in the number of crashes after an ITS deployment. This is known as the "history" threat to before-and-after evaluation validity (*31*).

For example, assume that an increase in law enforcement presence is a part of the post-ITS deployment in the study corridor. Also assume that an increase in law enforcement presence in the study corridor causes drivers to behave differently (such as to reduce speed, be more alert and attentive to driving, or to be less aggressive) and that changes in these behaviors can be measured. Finally, assume that a quantitative relationship can be shown between these changes in driver behavior and a reduction in the crash rate in the study corridor.

If the before-and-after study does not take this relationship between increase in law enforcement presence and reduction in crashes into account, then the benefits of the ITS deployment would be overestimated. The use of control sites that are similar to the site being evaluated and are not involved in the ITS deployment and experience the same increase in law enforcement presence as the study site is one method that would improve the before-and-after evaluation validity in this example.

Trends in the Value of MOEs Over Time

If the decrease in crashes in the after data is a result of a long-term trend that the analyst is unaware of and not due to the ITS deployment, then the evaluation will suffer from what is known as a "maturation" threat to validity (*31*).

Random Data Fluctuations

FHWA says "Crash data are particularly subject to random variations when measured over time or at a small number of locations." This threat to evaluation validity is known as "instability" (*31*).

APPENDIX D. ITS STUDY AREA: CUSTOMER SATISFACTION EVALUATION

BACKGROUND

There are a few important points regarding customer satisfaction that will greatly improve understanding and use of it as a measure of effectiveness in ITS projects:

- The satisfaction of individual users is an important element of a system's performance.
- Satisfaction can be reliably measured.
- Satisfaction is the difference between expectations and performance.
- Satisfaction is based on users' perception of performance, not on actual performance.
- Measures important to transportation professionals may not be useful as measures of the public's satisfaction.
- The elements of customer satisfaction cannot be accurately determined without data from the public.
- Input from the public is necessary not only in determining satisfaction, but also in developing appropriate measures.

Recognizing Satisfaction as an Element of Project Success

One key determinant of success is whether or not the people the project was intended to benefit are pleased with the outcome. While this idea seems straightforward, little has been done within the transportation industry to pin down the actual determinants of customer satisfaction. The *Highway Capacity Manual* has made progress by including some components of customer satisfaction in its level of service measures.

Two of the level of service measures included in the HCM – comfort and convenience – are directly related to user perceptions of service, while the others – speed, travel time, freedom to maneuver, and traffic interruptions – are more traditional measures that are easily quantified. In the chapter on urban streets, the HCM discusses LOS criteria, stating, "These criteria are based on the differing expectations that drivers have for the different kinds of urban streets." It later says, “These criteria vary with street class: the lesser the urban street (i.e., the higher its classification number), the lower the driver’s expectation for the facility and the lower the speed associated with the LOS.” It also states, “Each LOS represents a range of operating conditions and the driver’s perception of those conditions.” How are drivers’ expectations and perceptions to be gauged? Are they actually reflected in the boundaries that separate each LOS?

A focus group study aimed at discovering what really matters to users found that drivers do not perceive the distinctions in speed, maneuverability, and other factors used to determine LOS. When asked to delineate breakpoints, the participants did mention speed, but they did not correspond to the ones used in LOS determination (*33*). This difference suggests that, while LOS is an excellent tool for traditional evaluation of service, it may not be useful in judging satisfaction. Attempting to adapt old techniques for new applications will not yield correct and helpful data. Instead, decision-makers need customer-originated data that qualitatively describe what is important to system users and at what levels specific elements of performance become acceptable or unacceptable (*34*, *35*, *36*).   Recognizing that user impressions are a factor in the improvement of transportation facilities is a great start to creating satisfaction, but progress will only be made when transportation professionals go further than simply mentioning it. They must actually measure it.

Calculating Customer Satisfaction

In the past, measures of effectiveness have been based solely on transportation professionals’ assessments of what is acceptable and what elements are important. These measures are still useful in providing officials with a quantitative representation of transportation operations, but they do not effectively calculate customer satisfaction. In *ITS Benefits: Continuing Successes and Operational Test Results*, produced by the Federal Highway Administration in 1997, satisfaction is treated as something to be guessed at or estimated, not measured. The chapter on customer satisfaction states:

"Although satisfaction is difficult to measure directly, measures related to satisfaction can be observed including amount of travel in various modes, mode options, and the quality of service as well as the volume of complaints and/or compliments received by service providers"(*37*). The same statement can be found in the 1999 and 2001 updates of this report *(38, 39)*. Transportation managers should not limit their investigations to measures that seem to be logically related to satisfaction. For example, the measure of delay at a signalized intersection seems to be a logical determinant of satisfaction. In an effort to include satisfaction in the evaluation of projects, transportation professionals might calculate delay and call it a measure of satisfaction. This method, though it makes some sense, is not capable of definitively measuring satisfaction, because it does not include any customer-originated data. Instead, it seeks to convert performance data into satisfaction data.

As Pecheux, Peitrucha, and Jovanis have shown, delay, though a key aspect of satisfaction, is not the only component (*40*). They found that drivers perceived several other traits of service quality at signalized intersections, including:

- traffic signal efficiency,
- arrows/lanes for turning vehicles,
- visibility of traffic signals from queue,
- clear/legible signs and road markings,
- geometric design of intersection,
- leading left-turn phasing scheme,
- visual clutter/distractions,
- size of intersection,
- pavement quality,
- queue length,
- traffic mix,
- location,
- scenery/aesthetics, and
- presence of pedestrians.

Results showed that drivers evaluated service quality not based only on outcome, but also on the process of service delivery, i.e., the conditions and design of the intersections *(40)*. This result illustrates the necessity of conducting research that starts with a good premise. Though delay is a major component in satisfaction, assuming it is the dominant one and ignoring other contributing factors will prevent officials from maximizing satisfaction at intersections. Similar properties can be found for other aspects of the transportation system.

Discovering the Elements of Satisfaction

The reports and updates addressing ITS benefits summarize a host of studies on the success of ITS improvements. A good number of them involve surveys that address satisfaction, asking users if they were better off with certain improvements, if they were in favor of keeping the system, if the design was helpful, easy to use, reduced stress, and if users saved time. These are examples of measures related to satisfaction. However, a few studies go further, attempting to measure actual satisfaction and determining the elements that make up satisfaction, as well as the weight of each element in affecting satisfaction.

The results of satisfaction studies are rarely completely unexpected, but details about public preferences and concerns can be revealed when administrators attempt to discover what users want and what they consider to be important to project success. On the other hand, a study that makes no attempt to discover user wants and employs criteria decreed by officials – for example, asking if users are in favor of keeping the system – may not produce an accurate assessment of satisfaction. After all, drivers may think that they are better off after the start of a new project, but this doesn't necessarily mean they are satisfied with it. They may feel that they are only marginally better off and that much more could be done to enhance the design.

Obtaining Practical Data

Though the examples are few, recent studies have shown that satisfaction can, indeed, be measured and is a useful tool for the development of transportation systems. In a 1997 survey in Southern California, a majority of drivers indicated that they were content with the currently available traffic information, but they were also interested in more frequent updates and improved local road and street information. (See Figure D-30.)

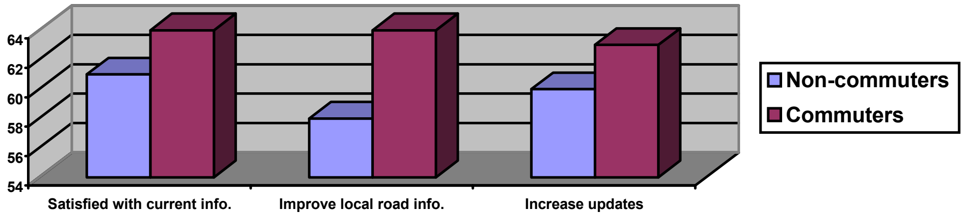

Figure D-30. Southern California Driver Satisfaction Survey Results.

In addition, the survey asked about drivers' interest in developing an advanced traveler information system and what attributes of that type of system are most important. The majority indicated that they would like to have in-car navigation and traffic information via television and radio, but they showed less interest in information via telephone and computer and information about public transit (*41*). The advantage of this survey is that it goes beyond measures that are related to satisfaction, such as travel time and delay. The questions involve actual satisfaction and, more specifically, what can be done to make users more satisfied. With this insight, providers can shape the service to more closely fit users' wishes, thereby achieving a higher level of satisfaction and more frequent use of the service.

In general, respondents in recent surveys on ATIS have described their use of the system and its benefits (*41, 42*) and identified specific developments that would encourage them to use the system more frequently (*43*). They have also described their willingness to pay for the service and what price levels they feel would be appropriate (*44, 45*). With these data, as decision-makers consider the development of ATIS, they will be able to shape their plans to suit the public's needs and develop the components of ITS the community is interested in, avoiding wasted tax dollars.

Satisfaction from the Customer's Point of View

Customer satisfaction or dissatisfaction is determined by the difference between expectations and performance. If customers receive service at or above the level they expect, they will be satisfied (*46*). Since customers will be satisfied or dissatisfied based on their assessments of the service they receive, their opinion of the level of performance is the only one that matters when gauging satisfaction. For this reason, it is essential that organizations measure not only the system performance, but also users' perceptions of system performance. It is understood in other service industries that "only customers judge quality; all other judgments are essentially irrelevant" (*47*).

Satisfaction as a Separate Measure

Though quantitative measures of performance, which are developed by transportation professionals, are practical tools in judging the efficiency of a system, they do not translate into public satisfaction. Even if transportation engineers meet their goals for system operation, if the goals do not correspond to what the community wants, the design will be disappointing from the public's point of view. For example, delay at a signalized intersection would not be a good measure of satisfaction if data show that drivers do not precisely estimate delay, but instead detect other properties that affect their perception. For this reason, it is essential that transportation professionals collect data specifically for the purpose of judging public perception.

A recent study, in which a series of surveys and focus groups involving transportation experts and users was conducted, illustrates the point. Participants were asked to rate the quality of service at local facilities, the importance of specific activities or improvements, and their funding priorities. Comparisons of the results show that decision-makers overestimated the importance to the community of repairing roads and increasing highway capacity and underestimated the public's desire for carpool initiatives, development of light rail, improved air quality, and their willingness to pay more taxes to achieve their goals.

Though officials correctly identified the fundamental aspects of system operation, they did not realize the weight of other concerns in the public mind. In addition, officials' understanding of the public's funding priorities was skewed, underestimating the desire for timed stoplights, courtesy patrols, and transportation for the elderly and handicapped. Participants' misconceptions about the cost of these types of improvements could be partly to blame for the unanticipated funding priorities. In this case, better communication with the public about the amount and sources of funds for transportation improvements might bring users' expectations into line with those of transportation professionals. Finally, results showed that the community did not feel there was as much opportunity to express opinions on transportation issues as officials thought there was (*48*, *49*).

Marketers have long recognized that there are considerable discrepancies between the way customers characterize service and rank the importance of elements and the way suppliers do. Managers often resist research that contradicts their intuition, seeing it as a criticism of past decisions (*42*). As in other industries, managers in transportation must be open to new knowledge about user expectations and assessments of performance if they want to develop customer satisfaction.

Putting the Data to Use

Though comprehensive data on customer perceptions of service and satisfaction are lacking, some organizations have independently begun to gather information relevant to their operations. In 2000, the FHWA used a random digital dial survey to ask users about their satisfaction with specific attributes of the highway system. (See Figure D-31.) With the evidence gathered, providers were able to gauge how well they had done in correcting problems since the last survey, as well as determine the main upgrades needed in the future.

On the section related to federal land, people ranked satisfaction with road safety in national parks lowest but ranked it highest in importance.

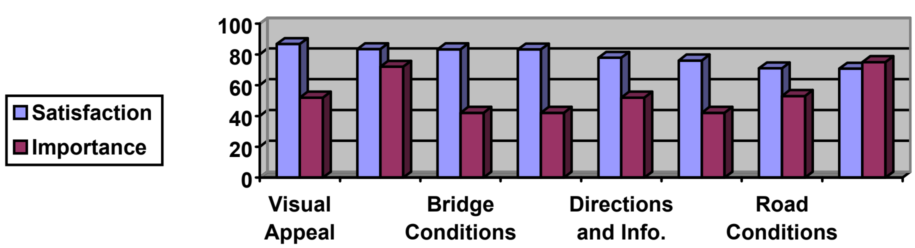

Figure D-31. FHWA Highway System Satisfaction Survey.

This insight is significant, in that it offers a chance to substantially improve customer satisfaction by correcting one feature of the system that people view as very important. In order to apply customer satisfaction data successfully, providers must take into account users' priority ratings, as well as their satisfaction ratings (*50*).

Taking a Proactive Approach

While studies to ascertain and improve customer satisfaction are an excellent way to correct existing facilities, a proactive approach, in which transportation designers incorporate user preferences and assessments of service into the decision-making process, provides an excellent opportunity to create user satisfaction from the very beginning of any project. A complete process, including 10 steps for involving the community in transportation decisions, was developed by transportation in Victoria, British Columbia, Canada (*51*). This process or others like it could easily be adapted to fit the needs of different communities with various goals. While many satisfaction studies are used to improve or simply determine satisfaction with facilities already in use, a proactive approach stresses the importance of addressing satisfaction during the planning process, before any decisions are made.

Correlating Qualitative and Quantitative Data

Though satisfaction data are essentially qualitative, they can be very helpful to administrators if they are correlated with the types of performance measures usually collected. In a 1998 study, researchers in Japan used a combination of surveys and field measurements to define quality of service from the user's perspective. Using surveys, the research team collected qualitative data on user perceptions of the quality of service for a selected rural road section. They then gathered corresponding quantitative data at the site using objective measures of effectiveness traditionally employed to evaluate quality of service. With these two types of data, researchers were able to find correlations between subjective and objective measures, providing transportation officials with a framework for incorporating user perceptions into the planning process. The results are shown in Table D-14.

Table D-14. Relationships Between Subjective Customer Satisfaction Measures and Traffic Measures.

Average Satisfaction Degree	Volume/ Capacity Ratio	Speed Difference Between 2 Lanes (km/h)	Inner Lane Utilization Ratio	Time Occupancy in outer (inner) lane (%)	Travel Speed (km/h)	Time Ratio of Car-following Situation	Number of Overtaking (/km)
Fairly Satisfied	0.28	>19	0.30	6(3)	>100	.20	0.16
Medium	0.60	>18	0.52	8(6)	>96	0.47	0.19
Somewhat Dissatisfied	0.85	>14	0.57	11(12)	>91	0.75	0.15
At Capacity	1.00	>4	0.52	26(29)	664	0.92	0.13

Though these data address only the conditions at a particular location, with more studies like this at a variety of facilities, a uniform correlation between satisfaction and quantitative measures of effectiveness could be developed (*52*).

Managing Expectations

Providers will frequently concentrate on enhancing performance to create satisfaction, but they can also have a role in shaping expectations. By studying public opinion before any decisions are made and incorporating it into the design of new facilities, planners can design a new project the way the public wants and expects it to be designed. By communicating with the public and realistically describing the services they will provide, planners can prevent users from forming inflated expectations that cannot be met.

As stated earlier, people are satisfied when their expectations are met. In order to achieve this goal, realistic expectations must be created through frequent communication between customers and providers. This communication will ensure that each group has an accurate picture of the objectives, predicted timeframe, estimated cost, and expected outcome of any new project. In *Managing Expectations: Working with People Who Want More, Better, Faster, Sooner, NOW!*, Naomi Karten provides a framework for managing expectations (*53*). A few of the guidelines are particularly apt for the purposes of the transportation industry.

Making Plans

If users' preferences are reflected in the design of a new project, the public will be satisfied with the purpose of the proposal. After that, transportation professionals must simply meet the stated goals of the project. Also, the public's awareness of the planning process, alternatives discussed, reasoning behind choices, and expected outcome will ensure that they do not envision a final product different from what is actually planned or from unrealistic expectations of what the project will accomplish.

Designers can help create an accurate picture for the public by avoiding conflicting and easily misunderstood messages.

Conflicting Messages

Conflicting messages can involve contradictions between:

- what you promise and what you do,
- what you imply and what you do, and
- what you say you won't do and what you do.

If any of these contradictions occur and are not clarified, the public will view officials as having fallen short of their stated objectives.

What You Promise vs. What You Do. The most obvious contradiction is between what is promised and what is actually carried out. When providers do not achieve the officially stated goals of a proposal, the public will feel cheated, often not realizing the difficulties and constraints that may have arisen to prevent the successful completion of the project. To this end, it is important that officials not promise what they can't deliver.

What You Imply vs. What You Do. Perhaps a more difficult contradiction to avoid is one between what is implied and what is actually done. In this case, providers may not even know that they have led the public to expect something other than what is actually planned, as each side will believe that the objectives are clear and that everyone has the same picture. Since implications are often made unknowingly by one side and accepted as fact by the other, both groups must continue to discuss the proposal even after a final decision is made, in order to clarify expectations.

What You Say You Won't Do vs. What You Do. A contradiction that may not always be viewed as a disadvantage is one between what you say you won't do and what you actually do. In many cases, if transportation professionals achieve more than the stated objectives, the public will be enthusiastic and more than satisfied. However, if it becomes a habit, the public might come to expect it and will be disappointed with anything else. For example, if new projects are consistently completed ahead of schedule, the public may come to view any project completed just in time as being late. The same can be said of a situation where costs are consistently lower than predicted or outcome is consistently better than planned. The public will come to expect results better than those officially projected. For this reason, transportation professionals should attempt to describe all projects as accurately as possible.

Easily Misunderstood Messages

Easily misunderstood messages include those with:

- confusing terminology,
- inadequate information, and
- ambiguity.

Confusing Terminology. Confusing terminology is anything that the general public will not understand. Measures such as throughput or lane-carrying capacity are not part of the public's everyday vocabulary and may not lead to new proposals being received enthusiastically. It is important that the users understand how a new proposal will affect them personally, and therefore, they need to be able to relate to the measures officials use to describe improvements. Of course, professionals will use many different measures in their evaluations, but measures used to describe benefits and outcomes to the public should be presented in layman's terms.

Inadequate Information. Statements with inadequate information can lead customers to form their own conclusions, which may or may not be correct, or to simply lose interest. If the public does not understand the objectives of a project, they might lose enthusiasm for it. If they do not understand why certain things are done, they might feel that there is no point in participating in discussions, since decisions do not seem to be made for any logical reasons. Either way, a lack of information could lead to lost support.

Ambiguity. Ambiguous statements are easy to make. They involve words that we use everyday but that we do not always define precisely. Words like ‘better’ and ‘faster’ could easily be used to describe the outcome of a proposed project. However, there is little chance that everyone will have a similar definition of these words. If a project is described in vague terms with no specific explanation, it is likely that the public will have overly high expectations. Concrete information on predicted improvements will keep expectations in perspective and in line with actual plans.

Envisioning a Solution

Transportation professionals and the public will approach any transportation problem from different perspectives, since the general public lacks the expertise that professionals use to make decisions. Officials can narrow this perception gap in how customers and providers view service by clarifying benefits during a new project’s development process. What exactly will the system do? How will it affect individuals and the community as a whole?

It is also a good idea to provide an opportunity for the public to try out new systems ahead of time in a simulation or demonstration. Of course, unlike some other industries, it is difficult for transportation professionals to provide an exact simulation of the final product of a proposal. However, officials can provide a computer demonstration at community meetings or on local television, or at the very least provide an outline of the exact changes the new system will bring about. This explanation provides an opportunity to allow the public to consider its preferences and, perhaps, request changes. It is especially useful if the public has previously expressed preferences that transportation professionals think are not optimal. The public will be able to visualize the results and might reconsider their preferences, taking into account officials’ views on better alternatives.

Finally, planners should give the public advance notice of any changes. This notice will give people a chance to rethink their expectations, so that the final product does not disappoint them. They also need to know the reasons for any changes, especially if the original plan was made using public input. Explaining why their preferences cannot be exactly matched and how the alternatives are as close as possible may prevent resentment.

Measurement Techniques

The measurement techniques that can be most easily applied to transportation, in general, and ITS, in particular, are:

- complaint management,
- questionnaires,
- surveys, and
- focus groups.

Complaints

Of the measurement procedures available, those involving evaluation of complaints are the easiest, because data collection is unnecessary, since the complaints already exist. However, studying complaints is generally understood to provide biased data, because customers are likely to report some types of problems more than others, and not all customers take action, even when they are extremely dissatisfied. A *Handbook for Measuring Customer Satisfaction and Service Quality* describes a measure called the impact score, in which experts identify things that have gone wrong and how they affected overall satisfaction, the goal being to minimize occurrences that have a highly negative impact on satisfaction and occur most often (*54*). Another technique involves focusing on critical incidents that make customers happy and unhappy, attempting to minimize negative incidents and improve the related conduct of contact employees when addressing problems (*48*).

While these methods can help to reduce the most severe instances of dissatisfaction, they do not address users' day-to-day experiences. Though critical incidents are significant, most people do not experience them regularly, and their impressions of transportation service are more likely based on the typical operations of facilities.

Questionnaires and Surveys

Other popular methods of measuring customer satisfaction include questionnaires and telephone surveys. These methods allow experts to address particular questions, but this can be a disadvantage if those who generate the survey are unaware of significant issues affecting customers. For example, the 2000 FHWA satisfaction survey results showed that only 20 percent of the dissatisfaction with highways was accounted for by specific factors addressed in the survey. The discrepancy signifies a need for more in-depth research, in order to fully understand the components of customer satisfaction *(50)*. In this instance, focus groups could have revealed the issues researchers failed to address and given more comprehensive data on previously identified issues.

Focus Groups

In general, a focus group discussion is more likely to center on what is really important to participants. A survey, though quicker and requiring less involvement from researchers, will often miss valuable feedback, because its precise structure does not allow for spontaneous comments and shifts in direction. If officials prefer to use a survey or questionnaire, they can use focus groups in the development process, to ensure that they address the principal concerns.

A study of commuters between Toronto, Ontario, and Hamilton, Ontario, in 2000 provided wide-ranging data on user perceptions of highway service. This study used focus groups, guided by a facilitator using a checklist and open-ended questions, to learn the features of an ideal commute and what would make a commute less ideal. Table D-15 is a quantitative summary of the focus group results, listing the number of times specific factors were mentioned, without prompting, by participants. The variation between groups shows the importance of conducting a few discussions with diverse groups to get a broad range of data. Although the summary of results makes the data easy to comprehend and analyze, it is the specific comments of participants that can be most useful in making improvements. During discussions, participants brought up traffic information signs and indicated that they liked the signs and wanted more detailed information, so that they would know exactly why things were happening and alternate routes they could take (*33*). With this type of input, transportation professionals can make almost immediate enhancements to the system, giving users what they want and making the traffic information system work more efficiently.

Table D-15. Summary of Number of Text Units (TUs) in which Main Factors Were Mentioned.

Factor	Focus Group 1 (TUs = 885)	Focus Group 2 (TUs = 892)	Total (TUs = 1777)
Travel Time	78 (9%)	25 (3%)	103 (6%)
Density/Maneuverability	50 (6%)	36 (4%)	86 (5%)
Road Safety	45 (5%)	36 (4%)	81 (5%)
Commuter Information and Communication	24 (3%)	41 (5%)	65 (4%)
Civility	21 (2%)	17 (2%)	38 (2%)
Photo Radar	2 (0.2%)	29 (3%)	31 (2%)
Weather	18 (2%)	5 (1%)	23 (1%)

Participants were responding to the questions: What would constitute an ideal commute? What would make a commute less ideal?

Reliability

There are potential problems for any type of technique, including bias, inconsistency, irrelevance to users, insignificance, and cost (*54*). Regardless of the method chosen, experts can ensure that they get the most accurate and useful data by applying triangulation, which is using more than one technique to corroborate findings. For example, a combination of surveys, critical incident techniques, and focus groups will prevent the weaknesses of one technique from skewing the data. Also, collecting data from multiple sources will bolster the validity and reliability of the research by allowing diverse viewpoints to be heard (*48*).

Customer Satisfaction as a Measure for ITS

Recognizing that customer satisfaction is a critical element of success in ITS, providers will achieve greater support if they acknowledge the needs of the individual traveler as being important, in addition to the need to make the overall network perform efficiently. While efficiency is a fundamental goal, when taken alone, it fails to adequately account for the significance of public input in creating a system that satisfies users.

Though the data for some attributes of ITS are more abundant than for others, examples of satisfaction studies can be found for most applications in the 1997 *ITS Benefits* and the 1999 and 2001 updates (*37, 38, 39*). The increased focus on customer satisfaction is apparent in the increase in available data with each report.

Easily Observed Services

ITS components with high visibility to users are especially suited to satisfaction studies, because users can easily separate these services from other aspects of the transportation system and because changes can be made relatively quickly compared to other facilities.
Two areas where customer satisfaction data are fairly numerous are transit and ATIS. Transportation professionals have successfully applied the results to make progress that translates into higher customer satisfaction. In transit, customer service surveys have been used to develop satisfaction, thereby increasing ridership, revenue, and support from the public, which may lead to a higher share of funding from taxes (*54, 55*, *56*). Users of ATIS, when asked, have given very specific suggestions for improvement of the system, including camera views, direct speed measures for highway segments, and travel times (*41, 42, 43, 44, 45*). Satisfaction data for traffic and weather information provided by signs can also be found. For elements such as electronic clearance, international border electronic clearance, and weigh-in-motion, user data could provide ideas on how to streamline the designs and make them more user friendly.

Unobserved Services

For applications such as network surveillance, probe surveillance, and weather data collection, where users are not aware of the behind-the-scenes operations or the usefulness of these components to other services, satisfaction is not an important measure. More obvious applications for satisfaction studies would be the services that use the unobserved components, such as traffic and weather information dissemination, to improve accuracy and efficiency. With these more visible services, users recognize particular instances of the system's successful or unsuccessful operation and can provide specific input as to what they like and do not like.

Services Usually Judged by Traditional Measures

Functions such as surface street control, freeway control, and HOV lane management are usually judged by travel time and delay. These measures are logically part of satisfaction, but as Pecheux et al. (*40*) and Hall et al. (*33*) have shown, users perceive characteristics other than the ones measured by traditional practices. While these other factors alone do not determine satisfaction, they do affect it, and therefore, should be taken into account when judging the success of a project.

Services with Safety as the Main Objective

For elements of ITS that the public may not notice or may not encounter every day, communication is key. The better the description of the service, the more accurate expectations will be, and the more publicity about successes, the better the public's judgment of performance will be. Since expectations and performance perception are the two elements of satisfaction, it is essential that officials make an effort to disseminate information to shape public opinion.

Incident management and service patrols, their purpose being to clear and prevent crashes, are usually judged by the rate of crash reduction. It might also be beneficial to discover the public's opinion of their effectiveness, using the data to correct or increase service or simply to effectively communicate with the community. The same can be said for railroad crossings and work zone management. Satisfaction data may not be used to alter the function of these systems, but they may be used to increase satisfaction by improving available information on the purposes and accomplishments of the systems.

The Necessity of Conducting Independent Research

It is unlikely that measures for customer satisfaction will be standardized. Needs and impressions vary depending on place and type of project. By asking people what they think of the existing system, what they want changed, and what they would like to see developed, designers can respond by creating a system that users will like. Errors in judgment and wasted resources are likely to occur if decisions are not based on solid data (*54*). In the past, providers have used quantitative data based on measures of effectiveness they deemed appropriate. Now that customer satisfaction has become a concern for many transportation experts, data should include qualitative elements based on criteria the public indicates are significant. Once the data are obtained, designers can concentrate on refining those elements rated high in importance but low in satisfaction to maximize results.

APPENDIX E. ITS STUDY AREA: ENERGY AND EMISSIONS EVALUATION

GOALS AND MOES

The purpose of an energy and emissions study is to estimate the impacts that ITS deployments have on fuel consumption and vehicle emissions. Fuel consumption is important from both an individual user perspective and from a system-wide perspective. From an individual user perspective, fuel consumption measure of effectiveness is gallons of fuel used per mile, and it is important because of its impact on user operating costs. From a system-wide perspective, fuel consumption is important due to its potential impact on the depletion of a non-renewable energy source. A system-wide MOE for fuel consumption is total gallons of fuel used in the transportation system. The primary measure of an emission is its concentration in the atmosphere, usually expressed as grams per cubic centimeter (g/cm^3). In addition, the total volume (expressed in tons) of an emission type that is present in the atmosphere is a useful MOE. Individual vehicle emissions are measured in grams per mile of travel or grams per trip.

Emissions are important from both a micro-level perspective, as well as from a system-wide perspective. For example, an emission such as carbon dioxide is important at the micro-level due to concerns of its health effects in “hot spots” or intense concentrations of CO_2 at locations such as intersection approaches or toll booths. Potential health effects of other emissions are more of a concern at the system-level, such as ozone, which is actually formed through a chemical reaction with individual precursor emissions such as nitrous oxides and volatile organic compounds (VOCs).

STUDY ISSUES

When conducting an emissions study, the analyst must be aware that estimating tailpipe emissions based on speed and VMT is not the only consideration. Initial start-up emissions, such as those associated with “cold-starts” and under-the-hood evaporative emissions are significant components of total trip emissions. In addition, ozone or smog is a secondary pollutant formed through a chemical reaction with individual precursor emissions such as nitrous oxides and VOCs whose formation is dependent on several factors, including the amount of various precursors present, wind speed, and ultraviolet light.

There are two basic methods of predicting emission impacts of an ITS deployment. The first method is to utilize the energy and emissions models embedded in the models utilized for the operational effectiveness study. If the energy and emissions models are not contained within the operational efficiency models, the second method is to take the outputs from the operational efficiency study (changes in VMT, speed, etc.) and input them into an air quality model. The next section describes some of the important issues related to the use of air quality models that predict emissions.

Predictive Modeling

MOBILE and EMFAC emission models are examples of models that predict vehicle emissions based on a relationship between average speed and tailpipe emissions. This relationship between vehicle average speed and tailpipe emissions is drawn from empirical testing done under the Federal Test Procedure (FTP). The FTP is supposed to represent an average vehicle speed/tailpipe emissions relationship and is sensitive to actual vehicle types and actual facility types being evaluated.

A National Cooperative Highway Research Program (NCHRP) study was conducted to develop and test potential improvements for assessing air quality impacts of transportation control measures (*57*). While TCMs are not identical to ITS technologies, there are some similarities in regard to the ability of air quality models to accurately evaluate the impacts associated with ITS deployments. The NCHRP study states that: "The existing assumptions built into the MOBILE and EMFAC models regarding the relationship between average speed and vehicle emissions do not enable the models to be used reliably to evaluate operational improvements that smooth traffic flow (e.g., ramp metering, signal coordination, and many ITS strategies). To the extent that such operational improvements reduce acceleration events and the queuing of vehicles, they may produce emissions benefits that are inconsistent with estimates based on the use of the speed correction factors presently built into MOBILE and EMFAC"(*57*).

Regarding facility-specific enhancements made during the study to current air quality models, the NCHRP study states: "The incorporation of facility-specific speed correction factors in the California EMFAC7F model leads to an increase in emissions of total organic compounds (TOC) and carbon monoxide (CO). This reflects the fact that freeway correction factors for both pollutants show higher emission levels at most speeds relative to the current correction factors. Similarly, there are significant increases in TOC and CO levels estimated for metered versus non-metered ramps. The comparison of NO_x levels is more complex because the freeway correction factor shows lower NO_x levels at most speeds relative to the existing correction factors, whereas the NO_x correction factors for metered ramps are above those of non-metered ramps. The estimated overall reduction in NO_x reflects the net of these two offsetting effects, with the decrease due to operation on all freeways offsetting the increase in NO_x on metered ramps"(*57*).

Therefore, it appears that air quality models such as MOBILE and EMFAC require adjustments to their emission factors before being used to evaluate many ITS strategies. Unless the enhancements made to the models during the NCHRP study have been incorporated into current versions of MOBILE or EMFAC, then the analyst should consider some type of manual adjustment to emission estimates under some ITS strategies.

BEFORE-AND-AFTER FUEL CONSUMPTION AND EMISSIONS – DATA COLLECTION AND ANALYSIS

If a before-and-after field data collection evaluation method is chosen, there are two options to consider.

Option 1

In option 1, floating-car studies are conducted on various facilities in the study network with hardware/software packages that estimate fuel consumption and emissions. Hardware attached to the transmission will monitor the vehicle's speed and/or acceleration profiles. Accompanying software will estimate fuel consumption and tailpipe emissions based on these profiles.

The algorithms being utilized within the software to make these estimations could be based upon the MOBILE and EMFAC air quality models. Therefore, manual adjustments to the emissions estimates might be necessary. (See discussion above on predictive modeling.)

The next step in this option would be to extrapolate results from the floating-car studies to the entire network vehicle fleet. Considerations include:

- different types of vehicles in network-wide fleet,
- non-tailpipe emissions during a given trip (e.g., cold-start, hot soak, etc.),
- conversion of the aggregate tailpipe emissions into an ambient concentration of each emission type, and
- ozone formation from precursor emissions (probably will require use of another model to estimate ozone impacts).

Option 2

Emission monitoring equipment could be utilized to measure concentrations of ambient emissions or to measure a sample of tailpipe emissions within the study network. The NCHRP Report 462 discusses the feasibility of using advanced air quality monitoring systems to evaluate the impact that TCMs have on air quality (*57*). We are assuming that the NCHRP study on estimating air quality impacts of TCMs is relevant to evaluating air quality impacts of implementing many ITS technologies.

The NCHRP study concludes that while technically feasible, the expense of employing the advanced air quality monitoring systems for measuring ambient air quality that are discussed in the report probably would mean that such an evaluation would only be conducted as part of a national-level research effort.

The use of remote sensing techniques to measure individual tailpipe emissions is considered feasible in the NCHRP study. An additional issue to consider, as in option 1, would be the method used to extrapolate the sample of tailpipe emissions within the study network for the entire network fleet.

APPENDIX F. ITS STUDY AREA: INSTITUTIONAL BENEFITS EVALUATION

In this study, "institutional benefits" will refer to the impact that ITS market packages have on the activities or tasks that public agencies perform. Activities of public agencies and professions involved in transportation-related public works projects can be broadly summarized as shown in Figure F-32.

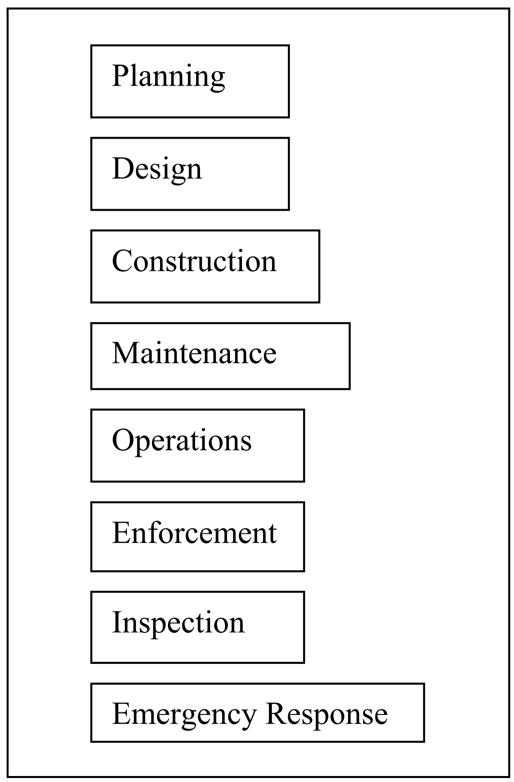

Figure F-32. Activities of Public Agencies and Professions Involved in Transportation-Related Projects.

The types of potential impacts that will be discussed in this appendix are primarily concerned with how public agencies and professions can do their existing tasks differently (e.g., planning studies, operations studies, post-project evaluation, traffic data collection, enforce traffic laws, commercial vehicle inspection, etc.) or how they can do new tasks altogether. Benefits to private or commercial drivers in terms of travel times savings, travel time reliability, and safety are addressed in other study areas, as well as societal benefits in terms or air pollution and consumption of natural resources.

INSTITUTIONAL BENEFITS STUDY METHODOLOGY

Institutional benefits as defined in this study include:

- cost savings of conducting the institutional task with ITS versus without ITS deployment,
- improvement in the quality of the institutional task (e.g., accuracy of transportation study results, thoroughness of commercial vehicle inspection), and
- usefulness of conducting a new task that would not be performed unless ITS was deployed.

The cost estimates of conducting institutional tasks with and without ITS deployment should consider:

- initial capital cost,
- annual labor,
- annual operations and maintenance costs,
- on-the-job injuries, and
- cost allocation (see the following discussion).

Cost Allocation

An ITS technology such as network surveillance will have multiple uses, one of which will be automated data collection for public agencies to utilize in various types of transportation studies. However, the purpose of implementing and maintaining the ITS technology is probably not to collect data for these studies but rather to use the data to operate the transportation network more efficiently.

Therefore, the issue arises of how much, if any, of the cost of the network surveillance system should be allocated to the purpose of conducting transportation studies or performing other agency tasks. In some cases, such as ITS market packages involved with commercial freight processing, it might be more obvious to allocate the entire cost of the technology to that particular institutional task.

The only recommendation we will make in this report concerning this issue of ITS market package cost allocation for institutional tasks is that it should be considered and that all assumptions made should be documented.

Steps in Methodology: Existing Task

1. Estimate cost of conducting existing task with and without ITS (including ITS deployment costs).
2. Estimate cost of expanding existing task (if applicable) with and without ITS (including ITS expansion costs).
3. Estimate quality of existing or expanded task with and without ITS.
4. Annualize all costs or calculate net present worth of all costs. Compare with and without ITS scenarios.
5. Consider the quality of the output of the existing or expanded task (in terms of accuracy, thoroughness, etc.) with and without ITS deployment.

If costs under the "With ITS" scenario exceed costs under the "Without ITS" scenario, decide if the quality and usefulness MOEs are worth the extra cost.

Steps in Methodology: New Task (that could not be performed unless ITS was deployed)

1. Estimate cost of new task with ITS (including ITS costs).
2. Estimate usefulness of new task with ITS.
3. Annualize all costs or calculate net present worth of all costs. Compare with and without ITS scenarios.
4. Consider the quality of the output of the new task (in terms of accuracy, thoroughness, etc.) with and without ITS deployment.
5. Consider the usefulness of being able to conduct a new task with ITS.

If costs under the “With ITS” scenario exceed costs under the “Without ITS” scenario, decide if quality and usefulness MOEs are worth the extra cost.

There are a few important points regarding customer satisfaction that will greatly improve understanding and use of it as a measure of effectiveness in ITS projects.

- The satisfaction of individual users is an important element of a system’s performance.
- Satisfaction can be reliably measured.
- Satisfaction is the difference between expectations and performance.
- Satisfaction is based on users’ perception of performance, not on actual performance.
- Measures important to transportation professionals may not be useful as measures of the public’s satisfaction.
- The elements of customer satisfaction cannot be accurately determined without data from the public.
- Input from the public is necessary not only in determining satisfaction, but also in developing appropriate measures.

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