ITS Performance and Benefit Study

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Final Performance and Benefits Summary

Executive Summary

The Final Performance and Benefits Summary describes our understanding of the connection between the National ITS Architecture, its technical performance characteristics, and its likely benefits for ITS users and suppliers. Ultimately, the goal of this analysis is to evaluate the National Systems Architecture in terms of its technical performance and its direct benefits for the ITS community. We have also included a discussion of transportation system benefits from ITS. The discussion of technical performance and benefits in this report describes both the characteristics of the architecture *per se* as well as the characteristics of ITS system designs that are based on the architecture. The purpose of this document, then, is to describe the Joint Team's assessment of the architecture performance and the level of benefits to system users and society as a whole. The first section discusses an assessment of the technical performance of the architecture, while the second section describes assessment of the benefits such an architecture might provide.

Technical Performance of the Architecture

In order to provide user services to public sector and private sector organizations, as well as individual travelers, certain technical questions about the architecture must be addressed. The level of benefits ultimately achieved from the architecture depends directly on its technical capabilities and performance. This document identifies the critical aspects of the architecture's technical performance and assesses how these aspects may influence ITS system implementation. More specifically, there are two fundamentally different pieces of the technical performance evaluation: 1) system performance, based on characteristics of the architecture alone and, 2) operational performance, based on specific ITS system designs. In these areas, we have used the technical and performance evaluation criteria proposed in Phase I, including:

<u>Systems-level performance criteria:</u>

1. *Support of ITS user services.* Does the architecture support the 29 user services across different time and geographic considerations? How well does the architecture support development and deployment of these user services?

2. *System flexibility and expandability*. Does the architecture provide a sufficient level of flexibility to accommodate potential changes in the technology or environment associated with implementation? Will the architecture easily accommodate geographic and technical growth, as well as new user services?

3. *Performance of variously equipped vehicles.* What are the differences in system performance and benefits accruing to vehicles equipped with different levels of technology? Are these differences acceptable?

4. *Multiple levels of system functionality.* Are there various ways that the user services might be implemented? If so, can the architecture support each of these ways?

5. *Incremental installation.* Does the architecture support an evolutionary deployment? Is there a clear evolutionary path leading to the full-blown architecture? Can the architecture be tied into existing infrastructure and technologies?

<u>Operational-level performance criteria:</u>

1. *Accuracy of traffic prediction models.* With the architecture, how well are we able to predict traffic patterns and travel times in the network?

2. *Efficiency of traffic monitoring and control.* How well can the architecture monitor traffic conditions? What level of traffic control is possible with the architecture?

3. *Efficiency of traffic management center.* What is the information processing capability of TMCs? What level of coupling is possible among various processing functions at the TMC? How will different TMCs be coordinated?

4. *Accuracy of position location.* What is an appropriate level of accuracy in determining vehicle locations within the architecture?

5. *Effectiveness of information delivery methods.* Can information be delivered in both a timely and reliable manner?

6. *Adequacy of communication system capacity vis-a-vis expected demand.* Is there sufficient capacity in the communications system to handle the many demands that may be placed on it? How may this change for different levels of market penetration?

7. *Security safeguards.* How well is the architecture protected from accidental or deliberate breaches of security?

8. *Map update.* What are the implications of the architecture for updating maps, both in the vehicle and in the communications infrastructure?

9. *System reliability and maintainability.* How will the architecture perform under different environmental and geographic factors? How will service upgrades be incorporated in the system? What effect will infrastructure failures and environmental stress have on the architecture?

10. *System safety in degraded mode operation.* How safe is the system during degraded modes of operation? What is the likelihood of different types of system failures?

The systems-level characteristics, in general, can only be evaluated at a highly qualitative level. However, more specific ITS designs can be evaluated both qualitatively and quantitatively: methods of collection, flow, processing, and dissemination of transportation data and information.

The analysis of the architecture's technical performance using these criteria is summarized in Table ES-1. This table presents a qualitative measure of the performance as well as a justification, summarizing the primary systems-level features of openness and flexibility found in the Joint Team's architecture. These systems-level descriptors of the architecture reflect an underlying philosophy that the National Architecture should retain the maximum level of flexibility so that a single specification may support deployments which will differ markedly across time and geographic regions.

In summary, the architecture itself provides significant support for ITS user services, as they may be deployed in various locations and over time, around the country. The architecture is inherently designed to maximize this flexibility in deployment. Open system interfaces will support modular and incremental development of ITS systems. The ultimate use of the architecture will result in some incompatibilities with existing systems, primarily those that use proprietary hardware, software or communications media. Nonetheless, the architecture has been designed to minimize these impacts.

Table ES-1: Summary of Systems Performance Criteria

Performance Criteria	Description
Support for ITS User Services	• Physical architecture and market packages provide traceability to the process specifications in the User Service descriptions • Medium to high level of deployment anticipated for non-AVSS user services in 20-year horizon
Flexibility and Expandability	• Open architecture (No proprietary systems) • Market packages are designed in a modular way, allowing incremental growth in levels of function and technical sophistication

Performance of Variously Equipped Vehicles	• Architecture assigns high degree of autonomy and functionality to the private vehicle for ATIS and AVSS market packages • Support for range of products and services at different levels of technical sophistication, and resulting level of travel time and safety benefits
Multiple Levels of System Functionality	• Several market packages with a common purpose but differing levels of function and technical capabilities; e.g. in ATIS and ATMS • Support for range of products and services at different levels of technical sophistication
Incremental Installation: Evolutionary Implementation	• Use of existing wide-area and dedicated short-range communications technologies suggests early implementation of many market packages • Implementation strategy considers technical dependencies and likely time frame for evolution and maturity of emerging (but necessary) technologies
Incremental Installation: Existing Infrastructure	• Maximal use of existing, mature technologies, especially through use of cell-based communications for wide-area mobile communications and emerging standards for short-range mobile communications • Emphasis on cooperative information sharing and joint information management between institutions • Support of standards to achieve interoperability where necessary (e.g., dedicated short range communications) and in support of jurisdictional/institutional cooperation • Avoid specification of standards for internal functions and processes

Using the evaluatory system designs, an evaluation of the performance of the architecture was performed. The results of this analysis are shown in Table ES-2. Summarizing, there is sufficient existing communications, database, and other information technology to handle most communication and information processing requirements of ITS. The area of greatest uncertainty at this time involves many of the sensors and technologies associated with advanced vehicle safety and control systems. Additional operational analysis of the architecture appears in the *Communications Document* submitted separately.

Table ES-2: Summary of Operational Performance Criteria

Performance Criteria	Description
Accuracy of traffic prediction models	• Market packages support a variety of data collection methods, including cooperative probe vehicles and video (CCTV) imaging • Flexibility in design of software for traffic monitoring and prediction
Efficiency of traffic monitoring and control Efficiency of TMC	• Sufficient wireline capacity to support data collection and aggregation with minimal delay • Sufficient wireline capacity to support inter-jurisdictional and inter-agency information sharing • Sufficient in-house processing power to support real-time information processing (30 to 60 second update cycle)
Accuracy of position location	• Support for broad range of existing positioning technologies (satellite- and terrestrial-based trilateration, fixed point referencing, etc.) • Support for emerging but immature high-accuracy technologies for AVSS applications
Effectiveness of information delivery methods	• Mobile communications delays of under 0.5 s for one-way transmission using cell-based technologies • Sufficient information retrieval and database management capability to support data queries in real time (1-2 seconds) • Total information retrieval time of 3 seconds for mobile queries
Adequacy of communications system capacity vis-a-vis expected demand	• Efficient use of available cell-based communications system capacity • Non-dedicated communications channel allows more efficient use of spectrum

Table ES-2: Summary of Operational Performance Criteria (Continued)

Performance Criteria	Description
Security safeguards	• Support for encryption techniques for communications • Support for user authentication and non-repudiation communications overhead where anonymity is not practical • Support for technologies and messages that preserve user privacy and anonymity • Support use of TCSEC criteria for rating and securing ITS databases
Map update	• Support for map update in off-peak periods using both wireless and wireline technologies; primarily for exception updates • Data loads and cost for wireline and wireless updates are significant
System reliability and maintainability	• Largely a function of system design and deployment conditions (i.e., architecture-independent)
System safety and availability in degraded modes	• Incorporation of systems ensuring data integrity and security • Support for design guidelines for improving safety in degraded mode operation • Minimal specification of architecture for high safety-critical systems that are still being defined (AVSS market packages)

Benefits of the Architecture

The benefits analysis separates two parallel types of benefits: 1) the benefits of the architecture as a whole to enhance the development of a market for ITS products and services; and, 2) the benefits of particular ITS products and services, as defined in the Joint Team's market packages.

First, the national architecture itself provides several advantages to help foster a market for ITS. The architecture itself enhances the ITS market by providing a common platform for systems integration, both at the level of the architecture and at the level of deployment. Perhaps more at the deployment level, the architecture will contribute to developing consensus standards for ITS interfaces and data exchange. Such standards have the following benefits and impacts:

- **Expanded markets and lower costs.** Open interface standards may result in an expanded market for ITS products and services, with resulting price competition and lower final costs to the end user. Such an expanded market may in turn result in network externalities, where simply having more users may mean additional cost reductions or increased benefits for users (e.g. route guidance, dynamic ridesharing, or regional traffic management).

- **Compatibility.** Open interface standards also provides many technical benefits to the end user, including: portability, inter-operability, and easier data exchange between ITS applications.

- **Technology innovation.** ITS standards may impede the long-term adoption of innovative technologies surrounding a given standard. For example, wide-area wireless communication standards for ITS could be "locked in" to a certain technology before more useful or cost-effective technologies have a chance. Thus, a standard may lead to an ITS industry settling on inferior technology. However, a standard may also serve to promote rapid technology development and innovation for specific components. The net impact on technology development is not easily quantified.

- **Vendor interests.** The long-term benefits of standards to ITS product and service vendors may be very favorable. In markets such as for ITS, industry consensus standards can result in the development or expansion of the market altogether. While there may be some natural resistance to standards from some large companies with high investment in proprietary systems, there may be considerable benefits to increasing market competition among both users and vendors.

A second major benefit of the architecture is the extent to which the architecture leverages integration of transportation functions, information flows and technologies. This integration is possible because the national architecture results from a comprehensive analysis of ITS user services. That is, the architecture suggests desired interfaces to achieve a comprehensive range of ITS services. The benefits of this integration include:

- **Data/information sharing for system management and planning.** Through the many data flows and interfaces, the architecture identifies how organizations can share data and information. In many cases, such information sharing is necessary to provide particular user services. Perhaps more importantly, these data and information can be used for better transportation system management and operations. Hence, the sharing of transportation performance data through the architecture may lead to more effective use of scarce transportation resources and better system-wide planning (e.g. with traffic and transit management, multi-modal coordination, etc.).

- **Common functions and functional integration.** There are many functions within the architecture that either 1) are common to several market packages or 2) may be integrated with functions in other market packages to provide higher benefits. By sharing certain functions between market packages, cost savings and operational efficiencies may be realized by the end users of these packages. In addition, integrating particular market packages allows higher benefits to be achieved. For example, route guidance can be connected with regional traffic control. This integration allows an ISP to provide better routing advice, given that they know the arterial and freeway signal plans. In turn, if the traffic managers know how vehicles will be routed, they can better time their traffic signals to accommodate this traffic.

- **Common technology.** Data flows and functions specified in the architecture may be combined, in a specific system design, to leverage common communications and other technology. Dedicated short-range communications devices can be used both for roadside toll collection, CVO vehicle check / clearance, and vehicle probe surveillance data. A single credit or debit card technology could be used for transit fare payment, toll and parking charges, or even non-ITS purposes. Software and hardware for map databases, as well as for position referencing systems (e.g. GPS), are needed for a broad range of ITS market packages, and can leverage system standards in these areas.

In addition to the benefits of the architecture *per se* cited above, the National Program Plan has specified a number of goals, or intended benefits, for ITS more generally. The level of benefits of ITS seems to be a function of both the overall magnitude of ITS services in general and also the specific system design. Moreover, the benefits are also a function of the existing and emerging transportation policies and programs at each location (as shown in Figure ES-1). In the figure, the shadowed boxes represent specific outputs of the architecture development program: the standards development plan, standards requirements, and the implementation strategy. The standards development plan identifies critical subsystem interfaces in the architecture and results in recommendations for required interface standards based on the message sets in the physical architecture. In addition, the architecture is accompanied by an implementation strategy, making recommendations on strategic policies and investment decisions related to both the architecture and its deployment through the market packages.

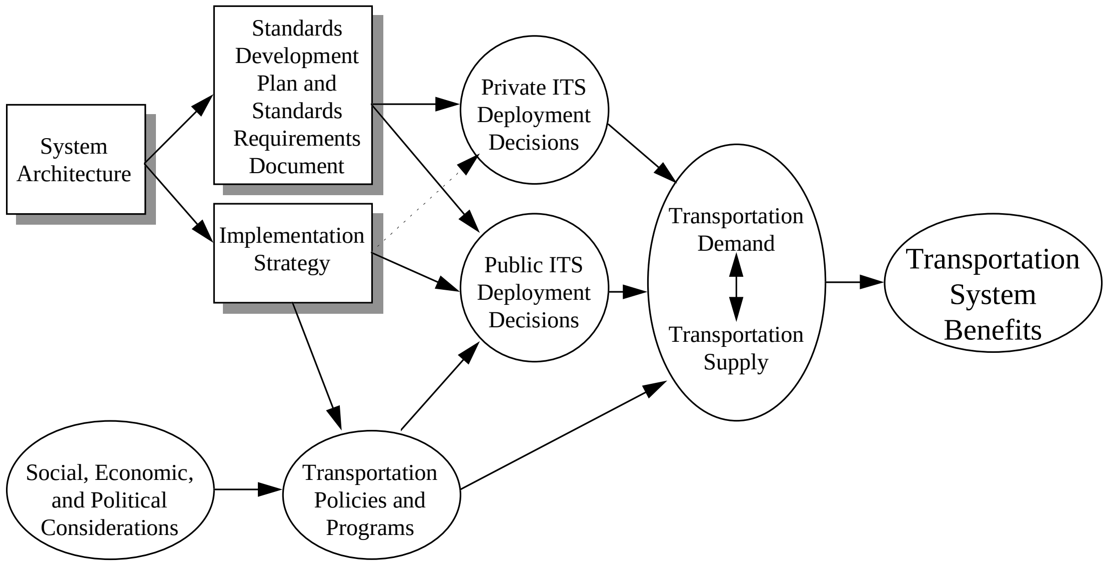

Figure ES-1. The Relationship of the ITS System Architecture to the Benefits

The implementation of particular ITS services, beneath the framework of the system architecture, must also be incorporated within the existing transportation planning process. Factors influencing and affecting these larger transportation planning objectives are shown in Figure ES-1 as ovals. Transportation policies and programs are shaped by broad social, economic, and political considerations. The development and deployment of ITS, as suggested through the implementation strategy, will ultimately need to be integrated within this larger transportation planning process. Thus, the ultimate deployment of the architecture will be a result of both the physical architecture itself and its implementation plan, but also with consideration for a broader set of transportation goals, policies and programs. The private sector, as a key participant in producing ITS products and services, may also respond to the recommendations of the national architecture.

Taken as a whole, the implementation of ITS market packages, and thus the ultimate level of benefits achieved by that implementation, depend on both the architecture and the extent to which broader transportation policies and programs support public and private investments in ITS. The national architecture, however, leaves the choice of an ITS system design (and resulting market packages) to these public and private decision-makers.

The results of the benefits assessment imply that, within the context of these private and public ITS implementation decisions, ITS may provide substantive benefits and will support particular transportation system goals. The particular features of the Joint Team's architecture that accentuate the likelihood of significant benefits from ITS include:

- Sensitivity to larger transportation planning and policy objectives
- System flexibility and openness
- System modularity
- Support for multiple levels of functionality and technical sophistication
- Leverage of existing infrastructure and communications systems
- Opportunities for interface specification and standards
- Deployment within existing institutional arrangements
- Effective allocation of costs and benefits

These features of the architecture, including both technical and non-technical features, enhance the development and longevity of an ITS market over the next 20 years.

The Joint Team has also developed qualitative judgments of the benefits that can be expected for each of the market packages. These projected benefits can be aligned with specific needs of a deploying agency to select the right market packages for deployment. Table ES-3 associates the market packages with the identified goals of ITS and the systems architecture development. As might be expected, different goals are supported by different groups of market packages. Also evident is that several of the market packages assist in attainment of multiple goals; such market packages are likely early winners that should be promoted through early deployments.

In addition, Table ES-4 describes the allocation of benefits by market package for both direct and indirect beneficiaries. To the greatest extent, this distribution further supports the objective of the architecture of providing benefits to those who pay (either directly or indirectly) for the services provided in these market packages.

Table ES-3: Benefits of Market Packages for Achieving ITS System Goals

	Market Packages	ITS System Goals: Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
APTS	Transit Vehicle Tracking	*	**	*		*	*
	Fixed-Route Operations	*	**	*		*	*
	Demand-Responsive Operations	*	**	*		*	*
	Passenger and Fare Management					**	*
	Transit Security				**		*
	Transit Maintenance					*	*
	Multi-modal Coordination	*	*			*	
ATIS	Broadcast Traveler Info	*	**	*			***
	Interactive Traveler Info	**	***	*			***
	Autonomous Route Guidance	**	***				***
	Dynamic Route Guidance	**	***	*	*		***
	ISP-Based Route Guidance	**	***	*	*		***
	Integrated Transportation Mgmt / Route Guidance	***	***	**	*		**
	Yellow Pages and Reservation		*				**
	Dynamic Ridesharing	**	*	*			*
	In Vehicle Signing		*		*		***
ATMS	Network Surveillance	*	*	*			*
	Probe Surveillance	*	*	*			**
	Surface Street Control	**	***	**	**		*
	Freeway Control	**	***	**	*		*
	Regional Traffic Control	***	***	***	**		*
	HOV and Reversible Lane Management	*	**	*			*
	Incident Management System	**	**	***	**		*
	Traffic Information Dissemination	**	*	*			*
	Traffic Network Performance Evaluation	**	**				*
	Dynamic Toll / Parking Fee Management					**	*
	Emissions and Environ. Hazards Sensing			***			**
	Virtual TMC and Smart Probe Data	*	*	*		*	*
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				***	**	**

Key: * = low benefit, ** = moderate benefit, *** = high benefit

TableES-3: Benefits of Market Packages for Achieving ITS System Goals (Continued)

	Market Packages	ITS System Goals					
		Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
AVSS	Vehicle Safety Monitoring				***		***
AVSS	Driver Safety Monitoring				***		***
AVSS	Longitudinal Safety Warning				***		***
AVSS	Lateral Safety Warning				***		***
AVSS	Intersection Safety Warning				***		***
AVSS	Pre-Crash Restraint Deployment				***		***
AVSS	Driver Visibility Improvement				***		***
AVSS	Advanced Vehicle Longitudinal Control	**	*		***		***
AVSS	Advanced Vehicle Lateral Control	**	*		***		***
AVSS	Intersection Collision Avoidance				***		***
AVSS	Automated Highway System	***	***		***		***
EM	Emergency Response	*		*	***	**	*
EM	Emergency Routing	*		*	***	**	*
EM	Mayday Support				***	*	**
ITS	ITS Planning	**	**	**	**	**	***

Key: * = low benefit, ** = moderate benefit, *** = high benefit

Table ES-4: Benefits Allocation of ITS Market Packages

MARKET PACKAGE	SOCIETY	TRAFFIC MANAGEMENT CENTER	TRANSIT MANAGEMENT CENTER	EMERGENCY MANAGEMENT CENTER	FLEET MANAGERS	FLEET DRIVERS	EQUIPPED TRAVELERS	UNEQUIPPED TRAVELERS	TRANSIT & HOV USERS
Broadcast-based ATIS							Direct	Indirect	
Interactive Traveler Information							Direct	Indirect	
Autonomous Route Guidance							Direct	Indirect	
Dynamic Route Guidance							Direct	Indirect	
ISP Based Route Guidance							Direct	Indirect	
Integrated Transportation Management/Route Guidance							Direct	Indirect	
Yellow Pages and Reservation							Direct	Indirect	
Dynamic Ridesharing							Direct	Indirect	Direct
In Vehicle Signing							Direct		
Network Surveillance	Indirect	Direct					Indirect	Indirect	Indirect
Probe Surveillance	Indirect	Direct					Indirect	Indirect	Indirect
Surface Street Control		Direct					Indirect	Indirect	Indirect
Freeway Control		Direct					Indirect	Indirect	Direct
HOV and Reversible Lane Management		Direct					Direct	Direct	Direct
Traffic Information Dissemination	Indirect	Direct					Direct	Direct	Direct
Regional Traffic Control	Indirect	Direct					Indirect	Indirect	Indirect
Incident Management System	Indirect	Direct	Direct				Direct	Indirect	
Traffic Network Performance Evaluation	Indirect	Direct					Indirect	Indirect	Indirect
Dynamic Toll/Parking Fee Management	Indirect	Direct					Direct	Indirect	
Emissions and Environmental Hazards Sensing	Indirect	Indirect					Direct	Indirect	
Virtual TMC and Smart Probe Data	Indirect	Direct					Direct	Indirect	

Table ES-4: Benefits Allocation of ITS Market Packages (Continued)

MARKET PACKAGE	SOCIETY	TRAFFIC MANAGEMENT CENTER	TRANSIT MANAGEMENT CENTER	EMERGENCY MANAGEMENT CENTER	FLEET MANAGERS	FLEET DRIVERS	EQUIPPED TRAVELERS	UNEQUIPPED TRAVELERS	TRANSIT & HOV USERS
Transit Vehicle Tracking			Direct						Indirect
Fixed-Route Operations			Direct						Direct
Demand Responsive Transit Operations			Direct						Direct
Passenger & Fare Mgmt			Direct						Direct
Transit Security			Direct	Indirect					Direct
Transit Maintenance			Direct						Indirect
Multi-Modal Coordination			Direct						Direct
Fleet Administration					Direct	Indirect			
Freight Administration					Direct	Indirect			
Electronic Clearance					Direct	Indirect			
CV Admin. Processes					Direct	Indirect			
International Border Electronic Clearance					Direct	Indirect			
Weigh-In Motion					Direct	Indirect			
Roadside CVO Safety					Direct	Direct			
On-Board CVO Safety			Indirect		Direct	Direct			
CVO Fleet Maintenance					Direct				
HAZMAT Management		Direct			Direct				
Emergency Response	Indirect			Direct			Direct	Direct	
Mayday Support				Direct					
Emergency Routing	Indirect			Direct			Indirect	Indirect	
Vehicle Safety Monitoring							Direct		
Driver Safety Monitoring							Direct		
Longitud. Safety Warning							Direct		
Lateral Safety Warning							Direct		
Intersection Safety Warning							Direct		
Pre-Crash Restraint							Direct		
Driver Visibility Improvemt.							Direct		
Vehicle Longitudinal Control							Direct		
Vehicle Lateral Control							Direct		
Intersection Collision Avoidance							Direct		
Automated Highway System							Direct		
ITS Planning	Indirect								

Final Performance and Benefits Summary

Chapter 1
Introduction

1.1 Purpose

This *Final Performance and Benefits Summary* describes the technical performance characteristics the transportation-related benefits of the emerging National Systems Architecture. The preliminary work in defining a National System Architecture, both in Phase I of this program as well as in Phase II, has clarified different methods that may be used to describe the architecture's performance. Based on this level of performance, the architecture may also be examined with respect to the benefits it affords to system users, non-users, and society as a whole. This document summarizes the Joint Architecture Development Team's approach to evaluating the technical and performance merits of the architecture and the ultimate benefits of implementing Intelligent Transportation Systems (ITS) to improve the nation's transportation system.

The Joint Team's architecture is intended to support the government-defined 29 user services. Based on the definition of the Team's physical architecture, we have chosen to develop a set of 53 market packages, reflecting both the physical architecture and what the end user will ultimately see. These market packages, falling into six broad service categories, are shown in Table 1.1-1. They are described in detail in the Team's *Implementation Strategy* document submitted separately. The architecture, through these market packages, is intended to support the FHWA-defined user services, and to provide a reasonable level of performance to the product and service providers, and to provide a high level of benefit to system users and to society as a whole.

The purpose of this document, then, is to describe the Joint Team's assessment of the architecture performance, and the level of benefits to system users and society. This document submission includes our detailed evaluation approach and the final results of the analysis, combining results from Phase I and additional work in Phase II.

To measure and evaluate the technical performance and benefits of a national ITS architecture, a reasonably comprehensive set of evaluation criteria has been developed and is outlined in Table 1.1-2. In the area of technical performance, these criteria include items from Attachment 5 of the original FHWA contract within headings *1.0 Technical Performance* and *2.0 Operational Performance.*

However, in contrast to Phase I, the Phase II benefits analysis has been modified to accommodate a number of various purposes, including:

1. Inform ITS and architecture implementation decisions;
2. Describe the benefits of the national ITS architecture; and,
3. Support the broad goals of the ITS program at large.

Table 1.1-1: ITS Market Packages

ITS Planning System	ITS Planning
Advanced Traveler Information Systems	Broadcast Traveler Information Interactive Traveler Information Autonomous Route Guidance Dynamic Route Guidance ISP Based Route Guidance Integrated Transportation Management/Route Guidance Yellow Pages and Reservation Dynamic Ridesharing In Vehicle Signing
Advanced Transportation Management Systems	Network Surveillance Probe Surveillance Surface Street Control Freeway Control HOV and Reversible Lane Management Traffic Information Dissemination Regional Traffic Control Incident Management System Traffic Network Performance Evaluation Dynamic Toll/Parking Fee Management Emissions and Environmental Hazards Sensing Virtual TMC and Smart Probe Data
Commercial Vehicle Operations	Fleet Administration Freight Administration Electronic Clearance Commercial Vehicle Administrative Processes International Border Electronic Clearance Weigh-In-Motion Roadside CVO Safety On-board CVO Safety CVO Fleet Maintenance HAZMAT Management
Advanced Public Transportation Systems	Transit Vehicle Tracking Transit Fixed-Route Operations Demand Response Transit Operations Transit Passenger and Fare Management Transit Security Transit Maintenance Multi-modal Coordination
Emergency Management Systems	Emergency Response Emergency Routing Mayday Support
Advanced Vehicle Safety Systems	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

Table 1.1-2: Architecture Evaluation Criteria

TECHNICAL PERFORMANCE

Support of ITS services
System flexibility and expandability
Performance of variously equipped vehicles
Multiple levels of system functionality
Incremental installation
    Evolutionary implementation
    Existing infrastructure
Operational characteristics
    Accuracy of traffic prediction models
    Efficiency of traffic monitoring and control
    Efficiency of traffic management center
    Accuracy of position location
    Effectiveness of information delivery methods
    Adequacy of communication system capacity vis-a-vis expected demand
    Security safeguards
    Map update
 	
System reliability and maintainability
System safety in degraded mode operation

BENEFITS

Architecture benefits
    Standards and inter-operability
    Systems integration
    Technology synergy
ITS benefits
    User travel performance
    Transportation system performance
    Transportation system safety
    Environmental quality and energy use
    Economic productivity
    Initiation of new industries

The benefits of the national ITS architecture may be articulated through three major areas, as shown in Table 1.1-2: Benefits of national standards and product inter-operability; benefits of system integration, and benefits of technology synergy. In this way, this assessment identifies the benefits that are intrinsic to the national systems architecture itself. In addition, the benefits of ITS to the transportation system have been outlined in the ITS National Program Plan in six national goals, also shown in Table 1.1-2. This document addresses the framework for analysis and a qualitative evaluation of attainment of these six goals.

1.2 Scope

The discussion of technical performance and benefits in this report is intended to evaluate the ultimate implementation of specific architecture elements. As such, the benefits evaluation is intended to support two areas:

1. Explain the architecture and its likely implications for local and private-sector implementations; and,
2. Recommend federal implementation decisions that result in cost-effective and highly beneficial ITS implementations.

From this perspective, this Final Performance and Benefits Summary serves primarily to support the *Implementation Strategy* and the *Standards Development Plan* documents submitted separately. This support would be realized through describing the performance and benefits of ITS services and of the architecture *per se*. The key effort at this point in Phase II is to make the Final Performance and Benefits Summary as relevant and meaningful to the implementation process as possible.

Much of the content in this report is intended to describe some of the ways we expect the market for ITS products and services to develop over the next twenty years. The performance of the architecture is, of course, clouded by the uncertainties of how markets that do not currently exist (for the most part) will grow and develop in this time period. The rapid changes that we have seen in the technology marketplace over the past twenty years makes it a very formidable challenge to determine the roles and market conditions of ITS technologies in the future. Greater uncertainty is added by considering the role of the private sector in developing, pricing, and marketing these ITS technologies. As a result, the performance of an ITS architecture, and of the elements of that architecture that may impact ITS implementations, is very difficult to imagine, let alone evaluate, for the future. Moreover, even a casual glance at the technical performance evaluation criteria in Table 1.1-2 demonstrates that most, if not all, of these factors will be market driven once ITS services are introduced to the market.

As a result, both the technical performance and benefits assessment parts of the architecture definition requires the meeting of both supply and demand for these ITS market packages. Many issues associated with the product and service provision are addressed directly in this document. These include issues regarding the support of the FHWA-defined 29 user services and the flexibility, expandability, and modularity of the architecture to grow out of the existing infrastructure and adapt easily to new technologies. Other questions regarding the needs for communications system and the information processing capabilities of the architecture are discussed in the *Communications Analysis* document submitted separately by the Joint team.

Other issues from the technical performance evaluation, especially the operating characteristics, are also dependent on this uncertain ITS market. For example, a "perfectly accurate" traffic prediction capability may be a stated ideal of the traffic management system, but in reality, the evaluation of accuracy depends more on whether the information is sufficiently accurate that drivers will desire and value that information. These types of performance measures will obviously depend on the availability and needs of a market for each of the market packages. More significantly, behind the market packages themselves, the architecture will define the real technical capabilities and the resulting level of benefits experienced by the end users of ITS products and services.

The market effects also drive the assessment of benefits of the system. The primary analysis of benefits from the architecture considers many possible implementation scenarios as far as twenty years in the future. The uncertainties of these projected conditions cannot be understated. While this document outlines some of the potential benefits of a systems architecture, there is also the greater uncertainty of the level of benefits possible based on the architecture's support of the 53 market packages in Table 1.1-1. The transportation market in the U.S. has seen many changes over the last thirty years, including an easing of the regulatory environment of local, state, and federal governments as well as more technically innovative methods of making the transportation system work. Examples include significant restructuring in the trucking and airline industries, the growth of overnight package services, information technologies for freight logistics, and even development and implementation of alternative fuels and electric vehicles. Such changes have brought about both large and small benefits (as well as problems) to the transportation sector, many of which could not be predicted when government or private plans were developed.

In the same way, the potential benefits of ITS technologies are also difficult to measure without a better idea of the forces bringing these user services to the transportation market. Many important factors that will bear directly on the level of benefits, such as the overall market acceptance of these technologies, are very difficult to capture in the benefits analysis. In light of these uncertainties, this analysis is limited to a more qualitative discussion of how the resulting response to the national architecture will benefit the transportation system most specifically and the U.S. economy most generally. The questions asked in the course of this analysis center on the value of a single national architecture, as well as the likely magnitude of transportation-related benefits from ITS and the sectors of society where these benefits may be realized.

1.3 Structure of This Document

This document is basically structured into two parts, the first covering the technical performance of the architecture and the second discussing the assessment of benefits. Section 2 details the results of this technical performance evaluation.

The benefits assessment, appearing in the second part of this report, is presented in a somewhat different manner. Section 3 describes the analysis objectives and an overview of the methods used to evaluate both the benefits intrinsic to the architecture *per se* as well as those connected with ITS services more concretely. It also briefly describes the necessary linkages of the latter transportation system-related benefits to specific ITS market packages, and links these benefits to the stated goals of ITS. Section 4 describes the benefits of the national ITS architecture in greater detail. This includes a discussion of the value of national ITS interface standards, which are assumed to provide substantial benefits for both the development and long-term inter-operability of ITS products and services. A second sub-section describes synergies that are possible from when systems are integrated, as suggested by the many inter-connections in the national architecture. Thirdly, the benefits of synergies in the adoption and use of various technologies within the architecture is described. Finally, Section 5 describes the results of the qualitative assessment of ITS benefits. To this end, this section identifies specific types of benefits that might be realized by different sectors of society, including the government, industry users (fleet operators), individual travelers, and society as a whole. A concluding section (Section 6) gives a summary of the performance and benefits analysis and offers some conclusions of these results for evaluating ITS goals and for support of architecture-compatible ITS implementations.

Final Performance and Benefits Summary

Chapter 2
Results of Technical Performance Evaluation

2.0 Overview

The national ITS system architecture is intended to provide a number of benefits which enhance transportation systems in the United States. In order to provide services to both public and private interests, it is necessary to address certain technical questions about the architecture. The level of benefits ultimately achieved from the national architecture depends directly on its technical capabilities and performance.

This section identifies the critical aspects of the architecture's technical performance and assesses how these aspects may influence ITS system implementation. These main elements of a technical appraisal of the architecture include:

1. System performance
2. Operational performance

For the purposes of this evaluation, we have classified the technical and performance Evaluation Criteria, also known as ECs, into two categories: system characteristics and operational characteristics, as shown in Table 2-1. This classification facilitates the selection and use of appropriate techniques for their evaluation. More specifically, the system characteristics describe features of the architecture *per se*, while the operational characteristics describe features of a particular evaluatory design that is based on the national systems architecture.

Table 2-1. Classifications of Technical Performance Evaluation Criteria

***(I) System Characteristics*:**	***(II) Operational Characteristics:***
-Support of ITS services -System flexibility and expandability -Performance of variously equipped vehicles -Multiple levels of system functionality -Evolutionary deployment	-Accuracy of traffic prediction models -Efficiency of traffic monitoring and control -Accuracy of position location -Effectiveness of information delivery methods -Adequacy of communication system capacity vis-à-vis expected demand -Security safeguards -Map update -System maintainability -System robustness

In general, the evaluation of system characteristic ECs relies more on qualitative assessment. For each system characteristic EC, we identify a set of important attributes that will capture a wide range of implications, and identify how the architecture satisfies these attributes. The evaluation of operational characteristic ECs requires both qualitative approaches and quantitative approaches such as communications system modeling.

Figure 2-1 illustrates the schematic relationships between the architecture, evaluation techniques, technical performance EC categories, and the deliverables (shown in shaded boxes). The physical architecture is represented by these components: subsystem functional allocation, equipment packages, market packages, and evaluatory (or exemplary) designs. These concepts have been explained in greater detail in other deliverables such as the *Physical Architecture* and the *Implementation Strategy* documents. Briefly, they can be conceived as steps in building the physical architecture. Defining functional allocation helps define related functions in each architecture subsystem, yielding the equipment packages. Combining the equipment packages across subsystems to get a complete and deployable set of functions defines the market packages. Finally, combining the market packages in a likely scenario for implementation forms a specific evaluatory (or exemplary) design of the architecture. The representative market packages are used as a means to span the architecture's capabilities and attributes. As such, evaluating the set of market packages enabled by the systems architecture provides a close indicator of the technical performance of the architecture. Thus, the technical performance evaluation builds primarily from the market packages, which are the basic building blocks for forming the various evaluatory designs.

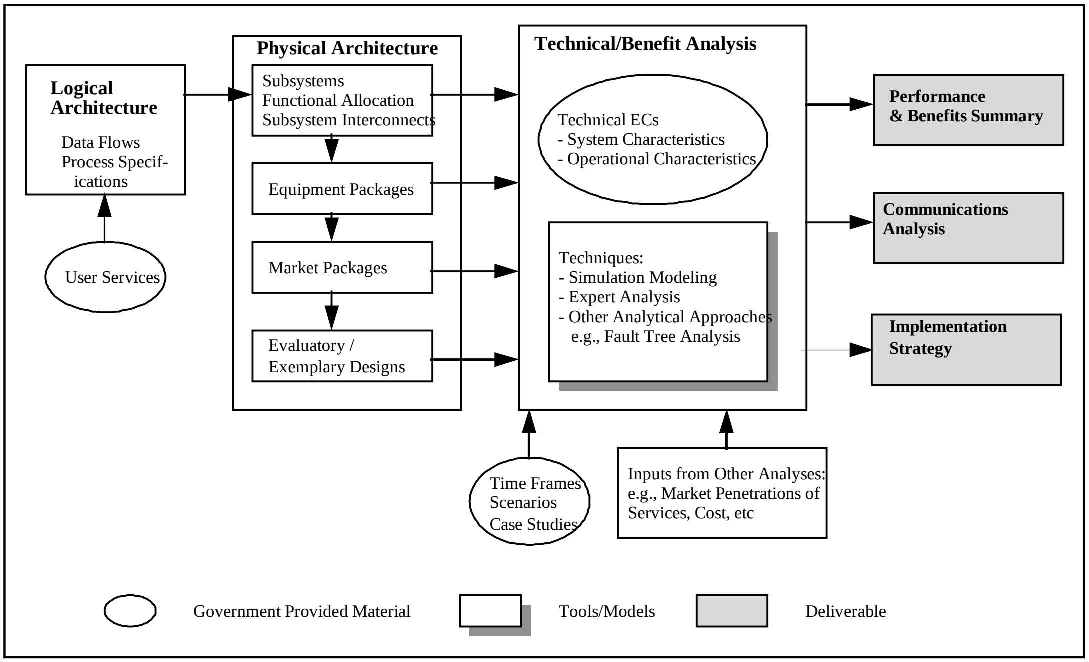

Figure 2-1. The schematic relationships between the evaluation techniques, technical performance EC categories, and the deliverables

Besides requiring market packages as inputs from the physical architecture, the Technical Performance evaluation also uses results from the other analyses, such as expected market penetration of the market packages. In addition, more detailed technical performance results will be reported in three other places in the deliverables: operational characteristics of the communications system are documented in the *Communications Analysis* document; and the *Implementation Strategy* document contains the implications of these evaluation results on ITS system implementations that may be developed from this architecture.

In this chapter, the evaluation results for the technical performance of the National Architecture are presented. Many of these results mirror those appearing in the Team's *Theory of Operations*, *Communications Analysis* and *Implementation Strategy* documents. To avoid duplication of material, a liberal use of references to these other documents are made here; the interested reader should be familiar with these other documents for a more complete picture of the architecture's technical performance.

Before describing the results of the technical/performance evaluation, it is helpful to review many of the distinguishing features of the Joint Team's architecture. The National ITS Architecture and evaluatory design define the units of deployment considered in this document. The 29 user services are provided through deployment and operation of equipment which is consistent with the physical architecture. In turn, the physical architecture defines the framework of interconnected subsystems and interfaces which govern ITS deployments to ensure national inter-operability. Though it forms the framework for deployment, the physical architecture is not specified with sufficient detail to define the incremental capabilities which will actually be purchased and deployed over time. The physical architecture is purposely maintained at a higher level to retain maximum flexibility so that a single specification may support deployments which will differ markedly across geographic regions and over time.

To provide the increased level of specification necessary for deployment analysis, a set of market packages and equipment packages were identified which address specific market segments with identified hardware and software components within the physical architecture framework. A market package addresses a distinct market need through a combination of equipment which consumers will purchase as an end-item; this equipment often resides in several physical architecture subsystems. Each market package consists of one or more equipment packages which segregate the equipment allocated to different subsystems (e.g., to the vehicle, to the roadside, or to the management center).

Both the physical architecture and market package representations are necessary to address technical system function and operations. The physical architecture coordinates overall system operation by regulating interfaces between equipment which may be deployed by different procuring and operating sectors. The market packages overlay a range of incremental capabilities and cost options on the subsystem framework that may be selectively implemented based on local requirements and resources.

2.1 System Performance

2.1.1 Support of ITS User Services

This criterion is intended to measure the extent to which the National Architecture supports the functions described for the 29 user services in Attachment #6 of the IVHS Systems Architecture Development contract. Most directly, the Joint Team's architecture supports all of the functions described in the 29 user service descriptions. This level of traceability from the physical architecture to the logical architecture to the user service requirements is addressed separately in the *Traceability Matrix* document. However, it is important to note that this level of support for the ITS user services is provided within the architecture. The interested reader is also referred to the *Theory of Operations* document, which describes in detail how the physical architecture provides each of the ITS services.

Moreover, because the Joint Team has chosen to represent its architecture through a set of 53 market packages, all of the requirements from the physical architecture are addressed in this set of market packages. The traceability between these functions in the market packages and the set of functions (actually, process specifications or P-Specs) in the logical architecture appears as an appendix in the *Physical Architecture* document. From this traceability, we know that the market packages provide support for a number of different user services by providing functions within the user services. In this way, we can identify the set of user services that are supported by a given market package, and we can identify the full set of market packages that are needed to fulfill all functional requirements of a user service. A matrix connecting market packages to user services in this way is shown in Table 2.1-1.

The other aspect of this criterion of Support of ITS User Services is the level to which these user services may be deployed across the set of time frames and geographic scenarios. Rather than examining the deployment of the FHWA's user services, our evolutionary deployment analysis has examined likely characteristics of the deployment of the *market packages*, described above. Within this context, a likely framework for deployment of these market packages is described in the *Implementation Strategy* document, suggesting what is believed to be the staged and incremental deployment of these market packages over the 20-year planning horizon, by geographic scenario (urban, inter-urban, and rural).

Finally, some projections are made about the level of deployment of functions within each user service, by time frame and scenario. This deployment is shown in Table 2.1-2, and shows the potential deployment of functions within the user services by time frame and scenario. Again, it is important to bear in mind that the level of deployment suggested here implies only that some of the functions within a given user service are intended to be deployed by a particular time frame in each scenario.

Table 2.1-1: Mapping of Market Packages to User Services

	User Services																												
Market Package	1.1 - PRE - TRIP TRAVEL INFORMATION	1.2 - EN - ROUTE DRIVER INFORMATION	1.3 - ROUTE GUIDANCE	1.4 - RIDE MATCHING AND RESERVATION	1.5 - TRAVELER SERVICES INFORMATION	1.6 - TRAFFIC CONTROL	1.7 - INCIDENT MANAGEMENT	1.8 - TRAVEL DEMAND MANAGEMENT	1.9 - EMISSIONS TESTING AND MITIGATION	2.1 - PUBLIC TRANSPORTATION MANAGEMENT	2.2 - EN - ROUTE TRANSIT INFORMATION	2.3 - PERSONALIZED PUBLIC TRANSIT	2.4 - PUBLIC TRAVEL SECURITY	3.1 - ELECTRONIC PAYMENT SERVICES	4.1 - COMMERCIAL VEHICLE ELECTRONIC CLEARANCE	4.2 - AUTOMATED ROADSIDE SAFETY INSPECTION	4.3 - ON - BOARD SAFETY MONITORING	4.4 - COMMERCIAL VEHICLE ADMINISTRATIVE PROCES	4.5 - HAZARDOUS MATERIAL INCIDENT RESPONSE	4.6 - COMMERCIAL FLEET MANAGEMENT	5.1 - EMERGENCY NOTIFICATION AND PERSONAL SECU	5.2 - EMERGENCY VEHICLE MANAGEMENT	6.1 - LONGITUDINAL COLLISION AVOIDANCE	6.2 - LATERAL COLLISION AVOIDANCE	6.3 - INTERSECTION COLLISION AVOIDANCE	6.4 - VISION ENHANCEMENT FOR CRASH AVOIDANCE	6.5 - SAFETY READINESS	6.6 - PRE - CRASH RESTRAINT DEPLOYMENT	6.7 - AUTOMATED VEHICLE OPERATION
Network Surveillance						✓																							
Probe Surveillance						✓																							
Surface Street Control						✓	✓																						
Freeway Control						✓	✓	✓																					
HOV and Reversible Lane Management						✓		✓																					
Traffic Information Dissemination						✓																							
Regional Traffic Control						✓																							
Incident Management System							✓																						
Traffic Network Performance Evaluation						✓		✓																					
Dynamic Toll/Parking Fee Management								✓						✓															
Emissions and Environmental Hazards									✓																				
Virtual TMC and Smart Probe Data		✓				✓	✓																						
Transit Vehicle Tracking										✓	✓	✓	✓																
Transit Fixed-Route Operations										✓	✓																		
Demand Response Transit Operations										✓	✓	✓																	
Transit Passenger and Fare Management											✓			✓															
Transit Security										✓			✓																
Transit Maintenance										✓																			
Multi-modal Coordination						✓		✓		✓																			
Broadcast Traveler Information	✓	✓									✓																		
Interactive Traveler Information	✓	✓									✓	✓		✓															
Autonomous Route Guidance		✓	✓																										
Dynamic Route Guidance		✓	✓																										
ISP Based Route Guidance	✓	✓	✓											✓															
Integrated Transportation Mgmt/Route		✓	✓											✓															
Yellow Pages and Reservation	✓	✓			✓									✓															
Dynamic Ridesharing	✓	✓		✓							✓	✓		✓															
In Vehicle Signing		✓				✓																							
Vehicle Safety Monitoring																											✓	✓	
Driver Safety Monitoring																											✓		
Longitudinal Safety Warning																							✓				✓		
Lateral Safety Warning																								✓			✓		
Intersection Safety Warning																									✓		✓		
Pre-Crash Restraint Deployment																											✓	✓	
Driver Visibility Improvement																										✓			
Advanced Vehicle Longitudinal Control																							✓						
Advanced Vehicle Lateral Control																								✓					
Intersection Collision Avoidance																									✓				
Automated Highway System																													✓
Fleet Administration																				✓									
Freight Administration																			✓										
Electronic Clearance															✓			✓											
Electronic Clearance Enrollment				✓											✓			✓											
International Border Electronic Clearance															✓			✓											
Weigh-In-Motion															✓														
Roadside CVO Safety																✓													
On-board CVO Safety																	✓												
CVO Fleet Maintenance										✓							✓			✓									
HAZMAT Managment							✓												✓	✓									
Emergency Response																						✓							
Emergency Routing																						✓							
Mayday Support												✓									✓	✓							
ITS Planning										✓																			

Table 2.1-2 Anticipated Level of Deployment of User Service Functions by Time Frame and Scenario

Time Frame	Scenario	User Service																												
		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.2	2.3	2.4	3.1	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	6.1	6.2	6.3	6.4	6.5	6.6	6.7
5 Year	Urban	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M	L	L							
	Inter-Urban	L	L	L	L	L	L	L	L		L	L	L	L	L	L	L	L	L	L	M	L	L							
	Rural	L	L	L	L	L	L	L	L		L	L	L	L	L	L	L	L	L	L	M	L	L							
10 Year	Urban	M	M	M	L	L	M	M	M	M	M	M	M	L	M	L	M	M	M	M	H	M	M	L	L	L		L		
	Inter-Urban	L	L	L	L	L	L	L	L		M	L	L	L	M	M	M	M	L	M	H	M	L	L	L			L		
	Rural	L	L	L	L	L	L	L	L		L	L	L	M	M	L	M	M	M	M	H	M	L	L	L			L		
20 Year	Urban	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L	L	L
	Inter-Urban	M	M	M	M	M	M	M	M	L	H	M	M	M	H	H	H	H	M	H	H	H	M	L	L	L	L	L	L	L
	Rural	M	M	M	M	M	M	M	M	L	H	M	M	M	H	H	H	H	H	H	H	H	M	L	L	L	L	L	L	

Blank = No Deployment of Functions within this User Service (< 1% of saturated market)
L = Low Deployment of Functions within this User Service (1 to 30% of saturated market)
M= Medium Deployment of Functions within this User Service (31% to 50% of saturated market)
H = High Deployment of Functions within this User Service (> 50% of saturated market)
* = Not applicable for this scenario

2.1.2 System Flexibility and Expandability

The systems-level criterion of flexibility and expandability refers to those characteristics of the architecture that make it technically flexible and expandable. First, in terms of technical flexibility, this criterion measures the degree to which the architecture accommodates or restricts different types of technologies, primarily with respect to:

- Communications media
- Sensor technologies
- Human interfaces
- Level of management center coordination
- Additional new services
- Centralized or distributed data base implementation
- Management center or third party information providers
- Algorithm enhancements

The characteristics of the Joint Team's architecture show that it is indeed flexible and expandable. The following points clarify the meaning of this flexibility and expandability in the context of the architecture.

- The National Systems Architecture is an open system that has no proprietary software, hardware, or communications restrictions. The architecture specifies the interfaces required between different subsystems and also allocates the functions among these sub-systems. Components, devices, and services that operate according to these interfaces are compatible with the architecture.

- The architecture specifies those interfaces in the architecture that require standards for national inter-operability, but does not otherwise restrict the development of new technologies by over-specifying other interfaces. A more complete discussion of interface specification and standards appears in the *Standards Development Plan* and *Standards Requirements* documents

- The architecture is modular. The architecture breaks the level of functionality from the 29 user services to a set of 51 market packages. These market packages as well involve a number of "equipment packages," representing a package that may actually be purchased by a particular end user. Thus, the level of functionality is broken down into considerably smaller pieces, with appropriate specification of interfaces between these pieces. All devices that are compatible with the interface specifications are thus compatible with the architecture.

- The National Systems Architecture may be deployed incrementally, adding capabilities over time and geography. Many of the market packages may be purchased as an add-on to support an existing bundle of services. The market packages thus form logical units from which modular systems may be developed and deployed over time. This aspect of the architecture is discussed in detail in the *Evolutionary Deployment Strategy* document.

Table 2.1-3 describes the level of flexibility in the National Architecture with respect to the particular measures described above. Based on the features of the architecture presented in Chapter 2.0, we believe that this architecture is very flexible and expandable.

Table 2.1-3: Architecture Features for Flexibility and Expandability

Criterion	Discussion

Communications media	• Architecture leverages existing cell-based wide area communications, which is compatible with most existing and emerging communications technologies. • Embraces commonalties in existing technologies and development of standards for short-range vehicle-to-roadside communications
Sensor technology	• Architecture accommodates all sensor technologies
Human interface	• Architecture does not specify any human interface standards or technologies
Management center coordination	• Architecture provides considerable level of inter-connection between management centers • Level of coordination and information sharing depends on cooperative agreements between jurisdictions
Additional new services - New functionality	• Architecture has a large number of subsystems (19) to absorb possible new functional requirements • Architecture allows a broad range of communications options (wide-area, short-range and vehicle-to-vehicle technologies)
Centralized vs. distributed data bases	• Database control is left at the discretion of local deployment
Management center or third party information providers	• Any management subsystem and traveler information provider subsystem may be co-located for efficiency; information provider may be public or private sector.
Algorithm enhancements	• No restrictions on the enhancements of software within the architecture

2.1.3 Performance of Variously Equipped Vehicles

The National Systems Architecture allows for a broad range of technical capability among vehicles that are equipped for various market packages. As noted in the summary description of the architecture features in Section 2.0, the architecture is able to accommodate different levels of technical sophistication and capability within each market package. The architecture specifies the interface between that device and other subsystems within the architecture, but there is no requirement placed on the level of functionality incorporated in the device beyond the interface. This means, for example, that personal or vehicle-based devices can have varying levels of capability (e.g., a cellular phone vs. a paging device) even for a single market package. This is most obviously true for the ATIS and AVSS market packages, where there is the need for some equipment on board the vehicle.

Also, the architecture has significant flexibility to accommodate different technologies and service delivery options. Particularly within the ATIS market bundle, the architecture provides a broad range of technical capabilities. Low-end users may take advantage of simple HAR and CMS systems provided publically, with only an on-board radio (for HAR). A low level of on-board equipment is necessary to receive more specific broadcast information (via the broadcast-based ATIS market package) through new equipment on board the vehicle. Higher levels of functionality and technical sophistication are embodied in the interactive ATIS market packages. Thus, we can conclude that the architecture does accommodate a broad range of ATIS equipment on board the vehicle.

Other market packages share similar advantages from the inherent flexibility of the architecture. For example, toll collection and electronic fare payment may be accommodated through either a credit or debit payment system, depending on the level of anonymity desired. In either case, the performance of these options for electronic payment services (toll collection, parking fee payment, transit fare payment) is extremely similar. The architecture accommodates interfaces between a common electronic payment instrument and an in-vehicle toll tag, or directly from the instrument to payment devices (e.g. a parking meter, a transit vehicle, etc.).

The other question which needs to be addressed in this citerion is the ability of the architecture to support individual benefits, depending on the level and type of equipment on board the vehicle. A review of the traffic simulation results from Phase I and the MITRE results from Phase II suggests that there are potential benefits across a broad range of users, based on the level of in-vehicle equipment. The story that can be told about ATIS devices is that travel time benefits can be achieved not only by those with sophisticated devices, but also by those with little or no equipment. Those fully-equipped vehicles in the simulation realized travel time savings benefits on the order of 10% of their trip travel time; however, there were also significant benefits to non-equipped drivers, who were able to reduce their travel times on the order of 5% simply due to the decreased congestion from the diversion of ATIS users.

Table 2.1-4 summarizes the benefits to users with different levels of ATIS and AVSS equipment. There are significant levels of functionality and benefits within the ATIS market bundle. While the AVSS market packages are still largely in the early stages of research and development, there has been only limited investigation of the capabilities of these safety-related systems to date. For this reason, we are not as confident of the level of different functionalities that might be deployed in the AVSS market packages. However, it is likely that the level of safety benefits to non-equipped vehicles will be small. For this reason, and because the architecture allocates significant functionality to the vehicle for the AVSS market packages, the aggregate score for the AVSS bundle is somewhat lower.

Table 2.1-4: Evaluation Of Architecture With Respect To Performance Of Variously Equipped Vehicles

Market Packages	Criterion			
	User travel time reduction	User safety improvement	Non-user travel time reduction	Non-user safety improvement
Broadcast Traveler Information	■	□	□	
Interactive Traveler Information	■	□	□	
Autonomous Route Guidance	■	□		
Dynamic Route Guidance	■	□	□	
ISP Based Route Guidance	■	□	□	
Integrated Transportation Management/Route Guidance	■	□	□	
Yellow Pages and Reservation	□			
Dynamic Ridesharing	□			
In Vehicle Signing	□	□		
Vehicle Safety Monitoring		■		□
Driver Safety Monitoring		■		□
Longitudinal Safety Warning		■		□
Lateral Safety Warning		■		□
Intersection Safety Warning		■		□
Pre-Crash Restraint Deployment		■		
Driver Visibility Improvement		■		□
Advanced Vehicle Longitudinal Control	□	■		□
Advanced Vehicle Lateral Control	□	■		□
Intersection Collision Avoidance		■		□
Automated Highway System	■	■		

Key: ■ = High benefit
□ = Medium to Low benefit
Blank = Little or No benefit

2.1.4 Multiple Levels of System Functionality

Multiple levels of system functionality refers to the capability of the architecture to support a number of different levels of functionality, both within each market package and across market packages. To this extent, the architecture first must be modular, so that different functions can be allocated to different areas within the architecture. As was mentioned in Section 2.1.2, the National Architecture is both modular and may be deployed incrementally across time and geographic areas. The level of granularity in the definition of the equipment packages allows us to say that the level of functionality may be defined to a fairly high level of resolution.

The level of technical sophistication possible within the architecture varies considerably both within each market package and across market packages. For the former, the architecture simply requires the appropriate interfaces for a new device or service to connect with other subsystems in the architecture. The level of functional specification within each particular subsystem allows a significant level of variation in the level of technical capability of these functions, allowing both high end and low end products and services to be used in the architecture.

At the same time, it is important to understand that the underlying possibilities for system functionality depend on the definition of interface standards. That is, to encourage multiple levels of functionality in ITS products and services, products must be inter-operable. The National Architecture effort is highly aware of the need for standard interfaces in ITS and the role that these interface definitions play in ensuring product compatibility and inter-operability. "Plug and play" capabilities are not possible without these standards: the interfaces affect both the operation of the market packages alone as well as how the market packages work together. The role of standards in the architecture is covered in more detail in the *Standards Development Plan* and the *Standards Requirements* documents submitted separately. Moreover, the specific benefits of standards are described in Section 4.2.

There are also a number of capabilities that span a number of different market packages, so as to accommodate a number of different levels of technical capability and cost. For example, the National Architecture supports a number of ATIS services through several ATIS market packages, including:

- Broadcast Traveler Information
- Interactive Traveler Information
- Autonomous Route Guidance
- Dynamic Route Guidance
- ISP Based Route Guidance
- Integrated Transportation Management/Route Guidance
- Yellow Pages and Reservation
- Dynamic Ridesharing
- In Vehicle Signing

Similarly, the architecture supports a low-end version of ATMS, through the virtual TMC and Smart Probe market package. More capable agencies may implement surface street control and/or freeway control market packages. Higher-end coordination between jurisdictions allows the regional traffic control market package. In this way, the ATMS market bundle includes market packages that may be added to the traffic management functions incrementally, based on the existing capabilities and desired level of service. Additional packages in this bundle, such as traffic network performance evaluation and traffic information dissemination, may be added at any time to reach a particular level of functionality in traffic management.

Many of these multiple levels of capability and functionality can be observed in Table 2.1-1. In this table, the Joint Team's market packages are mapped into the FHWA's 29 user services. For a given user service, there are a number of market packages that support the level of functionality within that user service. Simply by counting the number of market packages that support a particular user service, there are obviously a number of levels of market package functions that can be included in providing a particular user service. However, in many cases, not all market packages are absolutely necessary for a minimal level of service. Thus, the National Architecture supports many levels of technical capability.

2.1.5 Incremental Installation

This evaluation criterion is concerned with the capability of the architecture to accommodate and work with existing infrastructure, as well as the capability of the architecture to evolve as different ITS-related technologies also evolve. A range of technologies, each with unique performance, cost, and maturity characteristics can be applied to satisfy ITS functions through the market packages. The majority of these technologies are currently commercially available and expose ITS to little technical risk. The most problematic technology implications exist where a required ITS function is not supported by any cost-effective, commercially available technology.

In a few cases, required technologies may not exist or may be too costly and/or unreliable for commercial application. Market packages that are dependent on such technologies require further research and development to provide the enabling technology and integrate it into a commercially viable deployment package. This "technology dependence" for many of the ITS market packages is described in greater detail in Section 2.6 of the *Implementation Strategy* document.

2.1.5.1 Evolutionary Implementation

A review of the *Implementation Strategy* document (Section 2.6) indicates that, most generally, the types of technologies that one might expect to deploy in the near term are either mature or are mature with currently rapid innovation. Largely, with the notable exception of the AVSS market packages, many of the technologies envisioned with the market packages are mature. This an important characteristic of any ITS systems architecture. The communications systems for wide-area and short-range communications are currently mature, although many of these technologies are rapidly evolving. In addition, many of the position location, information management, and roadway and system-wide control measures have reached a significant level of technical maturity. Thus, the technical capabilities of the National Architecture definitely includes a strong element of compatibility with existing and mature technologies, especially in the communications and information management areas.

This level of technical maturity is reflected in the projections of market package deployment, presented in Section 2.1.1. There are a number of significant aspects of the technologies that work within the architecture:

- Because the architecture leverages existing (although possibly rapidly maturing) technologies, the market packages (and their implied user services) can be deployed early in the 20-year planning horizon.

- The architecture emphasizes expanding technical capability across geographic areas, as indicated by the level of deployment for urban, inter-urban, and rural scenarios. The level of deployment is generally highest in urban areas, where significant markets for technology may be identified, and gradually expands to other geographic areas as the familiarity and technical capability of the market packages grows.

- The architecture and its deployment strategy obviously assume very low levels of early deployment for market packages that depend on immature technologies. Among the non-AVSS market packages, several rely on somewhat immature technologies involving algorithms (for traffic prediction or route planning) or vehicle sensors. These areas are likely to experience more maturity in the middle-term future, and thus may be deployed in the 5- to 10-year time frame.

- The AVSS market packages are not expected to be deployed in the near future, as the technologies in this area are very immature, and will not likely be developed before the long term. These technologies include: vehicle status sensors (mixed), driver monitoring sensors, obstacle ranging sensors, lane tracking sensors, vehicle-to-vehicle communications, and vehicle control technologies.

In conclusion, the National Architecture is sufficiently flexible to accommodate the development of a number of requisite technologies. We have incorporated this development process into our thinking on the evolutionary deployment of the architecture. Nonetheless, we believe that it is a significant strength of the architecture that is takes advantage of existing and mature technologies for early deployment of the non-AVSS market packages.

2.1.5.2 Existing Infrastructure

For this criterion, we are concerned with two basic issues: (1) the current availability of technologies and associated components that support the National Architecture; and (2) the compatibility of these technologies with current infrastructure. The evaluation of the first measure is included in the information from the previous analysis (Section 2.1.5) and applies directly. That is, as was argued above, the National Architecture leverages existing technologies as much as possible in providing the market packages, thereby facilitating early deployment (at least from a technical perspective).

In the second measure, we are concerned about whether existing infrastructure is compatible with the technical systems that will result from the deployment of the architecture. One of the primary goals of establishing a national ITS systems architecture, however, is achieving nationwide inter-operability of devices and services to the end user. In order to accomplish this objective, interface standards and guidelines for technical development of systems are required in a number of circumstances. In the development, however, there is the risk that the standard excludes some existing infrastructure. Obviously, this is a risk that taken by any systems architecture and is not unique to ITS.

For Phase II of the architecture program, guidance for interface standards and compatibility with the Joint Team's physical architecture is presented in this and other documents. Section 4.2 of this document presents an analysis of the benefits and possible disbenefits of such standards. The *Standards Requirements* document submitted separately contains information on the need and priorities for ITS- and architecture-related standards. The *Standards Development Plan* presents information on the means of developing standards and the likely effect of these standards on the architecture itself. Finally, the *Implementation Strategy* document contains guidance to ITS implementors to determine compatibility with the National Architecture.

2.2 Operational Performance

2.2.1 Accuracy of traffic prediction models

One of the hopes of ITS is that we will be able to understand traffic patterns better so as to predict traffic flows and congested conditions. Such a technical understanding of traffic patterns could be useful both in terms of routing vehicles to avoid congestion (using ATIS and related market packages) as well as managing traffic to make the transportation system work more efficiently and effectively. To this end, the Joint Team has identified a separate market package that deals with the technical functions and information associated with traffic prediction: the traffic network performance evaluation market package.

As mentioned in Section 2.1.5, the algorithms used for traffic prediction and for incident detection are currently in a state of immaturity, technically. This is due in part to a lack of appropriate empirical data for analyzing and understanding traffic flow and driver behavior. While this data is still elusive, the fact is that a traffic management center (TMC) or traveler information provider would still like to have the functionality to predict traffic patterns. Several questions naturally arise out of the desire for this capability:

- What data may be available to predict traffic patterns?

- How can that data be processed in real time to provide important information about impending traffic conditions?

- What difference will this traffic prediction capability have on the transportation system?

As part of the analysis in Phase I, the four teams investigated these questions using the traffic simulation modeling tool of Integration. The results of this traffic simulation work have a number of implications for the value and accuracy of traffic prediction models, in the areas of data collection techniques, data processing and algorithms, and the potential improvements in traffic efficiency. These are discussed separately below.

2.2.1.1 Data Collection Techniques

Within the National Architecture, there are a number of ways of capturing traffic information:

- Traffic detection using traditional (e.g., loop) detectors ase well as audio (detectors) and video, based on the network surveillance market package;
- Cooperative probe vehicles, through the probe vehicle surveillance market package; and,
- Logging of route plans, through the interactive ATIS with infrastructure route selection market package.

A preliminary (perhaps obvious) observation about traffic data collection indicates that the level of data available has some impact on the ability to estimate current traffic conditions. When the detector deployment density was decreased from 100% of the links to 50% of the links in the traffic simulation, the capability to estimate travel times decreased, resulting in 2-3% increases in network travel times and vehicle stops for ATIS-guided vehicles. This suggests that the ability to identify current traffic conditions is hindered by the fact that data on many of the links in the network are not available.

On the other hand, our preliminary analysis using the traffic simulation results suggests that a probe vehicle density of about 2% (of all system vehicles) provides data on current traffic conditions as well as a 100% deployment of detectors (i.e. on all links in the network). These preliminary figures suggest that there can be a significant substitution of probe vehicle data for traditional detector data (or vice versa) in determining existing traffic conditions. A separate analysis of probe vehicle data in the communication system modeling (described in the *Communications Analysis* document) suggests that there is sufficient capacity in the Urbansville wireless communication network to handle 10% probe vehicles (with perhaps only small incremental value in traffic flow estimation or prediction). However, it is important to note that one evaluatory design (using CDPD) based on the National Architecture is able to accommodate significant probe vehicle messages as a form of traffic data collection.

The third method of data collection, using infrastructure logging of route plans, is valuable for two reasons: (1) the vehicle thus gives a sense of traffic volume and OD patterns to traffic management for estimating current and predicted travel flows; and, (2) the vehicle may also provide probe data (as above) to the traffic management center while on route.

2.2.1.2 Traffic Data Processing and Algorithms for Traffic Prediction

The overall level of data processing as part of assembling traffic information is discussed as part of Section 2.2.2 (Efficiency of traffic monitoring and control) and Section 2.2.3 (Efficiency of the traffic management center). Here, we repeat the observation made in Section 2.1.5 that the algorithms currently used for traffic prediction are very much in a state of immaturity. For this reason, it is unreasonable to comment on the types of algorithms or algorithm enhancements that might be developed in the short- to medium-term. Within the evaluation of the Joint Team's architecture, it is simply important to identify that the architecture is able to accommodate updates in algorithms and methods of traffic prediction (i.e., the architecture is flexible and modular with respect to software functionality and upgrades).

2.2.1.3 Effect on Transportation System Efficiency

While there has been a considerable amount of research effort expended into traffic modeling and prediction, the Phase I results we have from the Integration traffic simulation suggest that the ability to predict future traffic conditions is more art than science, and has little effect on the transportation system efficiency. The use of historical and current traffic patterns to optimize system-wide traffic signal timing, as put into effect through the (albeit outdated) Webster and Cobbe algorithm, suggest that there is no improvement in system-wide measures such as travel times and number of stops. While it is difficult to draw a conclusion based on this limited and outdated simulation analysis of this form of signal timing, the results would suggest that the potential improvements in traffic management, due to traffic prediction capabilities at a TMC, are not significant. These results point to two major issues: (1) the state of algorithms for traffic prediction are still very crude; and, (2) there is still little evidence to support the value of predictive travel time information for ATMS purposes.

2.2.2 Efficiency of traffic monitoring and control

With respect to many of the transportation management subsystems in the National Architecture, there is concern for the efficiency of information management. These management subsystems must collect, process, and disseminate a large amount of information about travel patterns and system operation, with a desire for such capabilities to be performed in real time.

Section 2.2.1 identified several areas of data collection for traffic management, including traditional infrastructure-based vehicle detection as well as probe vehicle messaging. From the communications simulation results, it appears that the types of delays in communicating this information to the traffic management center will be acceptably small. The transmission delays in the wireline system are typically well under 1 millisecond. The probe vehicle information may also experience small delays in wireless transmission to the traffic management center: these delays may be expected to fall below 0.5 seconds (1-way messaging) with a single dedicated CDPD channel, and would obviously be considerably smaller (at most 0.1 to 0.2 seconds) if a second dynamically-allocated channel were added to handle the peak communications loads.

Another aspect of the efficiency of traffic monitoring and control is the ability to process incoming data with reasonable speed so that traffic status can be known in real time. In a large urban area such as Urbansville, these requirements translate into a need for significant processing power. Approximate 260 blocks per second (about 100 kbps) of probe vehicle data will be arriving at the traffic management center in peak periods (at 2% market penetration of probe vehicles), although the actual quantity of meaningful probe data is probably about 14 kbps, as there is considerable overhead associated with the RS block size in the communications analysis. Also, the total wireline data load from traffic monitoring devices (excluding CCTV) is 250 kbps at a single TMC. In turn, the data rates back out of the TMC for traffic signals and other management functions is about 190 kbps. Additional communications with other TMCs, emergency management center, transit management center, and a traveler information provider increases the wireline data loads to 275 kbps incoming and about 215 kbps outgoing.

To handle these data rates in a large metropolitan area such as Urbansville, we anticipate the need for about 10 workstations with the capability of 100 (or more) Mips. This kind of processing power will be necessary to provide traffic information in real time to traffic managers, perhaps updated every 30 to 60 seconds. The operating concept for information processing and database management is to perform as much analysis as possible off line, and allow updates to databases on an exception basis, thereby reducing the amount of transaction time with the database. More details on the operations and information management aspects of the architecture are included in the *Physical Architecture* and the *Theory of Operations* documents.

Given these capabilities, the traffic management center may be able to determine traffic conditions with about 30 to 60 seconds of lag time, and then can use this information to update traffic management and control measures, such as the signal timing. However, the operating concept for TMCs does not require updates of traffic management parameters, such as traffic signal timing plans, this frequently. Signal cycle lengths, and basic random variation in traffic flows, would suggest that updates of signal timing plans in under 10 minutes are not practical. Moreover, the results of the traffic simulations presented in Phase I suggest some skepticism about the level of potential benefits of frequent updates of signal plans based on changing traffic conditions.

Based on these preliminary performance measures, the National Architecture seems to provide sufficient flexibility and technical capability to accommodate the data collection, processing, and dissemination that needs to occur for traffic monitoring and management.

2.2.3 Efficiency of traffic management center

The efficiency of the traffic management center has been discussed at length in Section 2.2.2, describing the efficiency of traffic monitoring and control. One issue which is worth describing in additional detail here is the level of coordination between TMCs and the level of coordination and cooperation between a TMC and other transportation-related management centers (information service providers, transit management centers, emergency management centers, etc.). The technical performance of the architecture in these regards is described briefly below.

The *Communications Analysis* describes the desired level of wireline connectivity between TMCs and between a TMCs and other management centers. Data rates between TMCs choosing to share basic traffic flow and signal timing information amounts to sharing about one megabyte of information every 20 to 30 minutes in the Urbansville scenario. This may be accomplished through a dedicated FDDI communications system, or perhaps through ATM/Sonet or other higher-capacity dedicated lines.

Additional data rates to other centers, such as the emergency management center, are expected to be considerably smaller - on the order of 100 to 200 kilobytes every 20 to 30 minutes. This information could be accommodated through a smaller capacity dedicated line, as might be desired for an emergency management or traveler information provider, or through a dial-up line, such as to a fleet manager or transit management center.

The National Architecture allows sufficient flexibility in the deployment so that a particular region may be able to select appropriate wireline connections that fit in with existing and locally desirable technologies. The data rates suggested by communicating between TMCs and from TMCs to other transportation service providers indicates that these loads are very much secondary to the concern for collecting and processing roadside detection information (as discussed in Section 2.2.2).

2.2.4 Accuracy of position location

There are a number of existing technologies which determine absolute position. Examples include GPS and other systems which apply trilateralization to known locations, either terrestial or space based. Augmenting these technologies are those that measure travel path and distance (e.g., odometer, compass, gyroscope) from a known location. Current GPS systems with differential correction are able to handle location referencing to within a few meters, while very high-precision systems (under 1 meter) associated with vehicle control applications is one remaining research area.

Table 2.2-1 shows the type of accuracy we believe is necessary to provide reliable position location information for the market packages within the architecture. The architecture supports a broad range of positioning technologies, including satellite and terrestrial trilateralization methods at the higher end of technology as well as the simpler "dead reckoning" technologies with frequent fixed point referencing to ensure an acceptable level of accuracy and reliability.

Table 2.2-1: Anticipated Position Location Needs

Market Packages	Recommended Accuracy
Interactive ATIS with Infrastructure Driver and Traveler Information	5 to 20 meters
Mayday Support	5 to 20 meters
Network Surveillance	50 to 100 meters
Probe Surveillance	25 to 50 meters
Virtual TMC and Smart Probe	25 to 50 meters
Emissions and Environmental Hazards Sensing	5 to 20 meters
Traffic System Maintenance	25 to 50 meters
Transit Vehicle Tracking	5 to 20 meters
Transit Security	5 to 20 meters
Vehicle Tracking and Dispatch	25 to 500 meters (local vs. long haul)
Material Tracking and Response	25 to 500 meters (local vs. long haul)
Longitudinal Safety Warning	Under 1 meter
Lateral Safety Warning	Under 1 meter
Intersection Safety Warning	1 to 5 meters
Pre-Crash Restraint Deployment	Under 1 meter
Driver Visibility Improvement	Under 1 meter
Advanced Vehicle Longitudinal Control	Under 1 meter
Advanced Vehicle Lateral Control	Under 1 meter
Intersection Collision Avoidance	Under 1 meter
Automated Highway System	Under 1 meter
Emergency Response	25 to 50 meters
E-911 Interface	25 to 50 meters

2.2.5 Effectiveness of information delivery methods

As identified in Section 2.2, there are a number of measures to characterize the performance of the communications system in delivering information to users, including gross information throughput, average link throughput, and link delay statistics. These measures are of primary concern in the wireless portion of the communications system, as wireless channel capacity is limited. In wireline systems, there is no reason to expect that information delivery will be hampered except through system-level hazards (e.g., a wire is cut); such issues are addressed in the criteria under the operational criteria described in Sections 2.2.9 and 2.2.10. For this reason, we focus on wireline communications here.

The communications simulation analysis suggests that a single dedicated CDPD channel is adequate to handle considerable ITS-related traffic in the Urbansville scenario. From the analysis of data loading requirements, we believe that the total wireless data load will be around 14 to 16 blocks (RS blocks) per second per sector in the 20-year Urbansville scenario. Link delays for a CDPD channel in the Urbansville CBD are generally still under 0.6 seconds (one-way link times) for over 0.6 Erlangs of throughput per sector (which also includes a 10 dB penalty for the CBD). Delay times in more outlying sectors suggest delays largely under 0.4 seconds for up to 0.6 Erlangs per sector. This implies that using CDPD or other cell-based technology, mobile communications adds approximately 1.2 seconds at most to the time between the information request and the receipt by the mobile user. Combined with an information query time at a management center of approximately 1-2 seconds, and negligible delay in wireline between the cellular base stations and the management center, a mobile user will on average have a request for information processed in under 3 seconds.

At higher levels of wireless system use, the delay increases more substantially, such that at 0.7 to 0.8 Erlang, delay times reach almost 1 second (one-way links). This may add considerably more time to the processing of a user request. However, when this single CDPD channel is augmented by a dynamically-assigned voice channel (when voice activity is low, for example), significantly more traffic can be accommodated. Capacity of such a system allows average delays of under 0.2 seconds well past 1.0 Erlangs of throughput. Thus, even under conditions where wireless demand is considerably higher than we expect, the dynamic allocation of excess capacity allows considerable reduction in wireless delays.

For the purposes of examining potential information delivery to mobile users, the above discussion highlights the anticipated performance of a cell-based communications system. More detailed analysis of the communications system performance appear in the *Communications Analysis* document.

2.2.6 Adequacy of communications system capacity vis-à-vis demand

A cursory discussion of the adequacy of communications system capacity with respect to the anticipated data loading is provided in Section 2.2.5. As is mentioned there, a more detailed analysis and summary of communications system performance is included in the *Communications Analysis* document. That document also includes a broad assessment of the capabilities of various potential technologies for the ITS communications layer. The reader is referred to that document for more specific information on the expected communications system performance.

2.2.7 Security safeguards

For the purposes of this document, we have broken down the types of security safeguards into those issues with communications security and database/information security.

2.2.7.1 Communications Security

Communications security deals with potential infiltration of the communications system function. There are a number of countermeasures designed to ensure a higher level of communications security; these measures are discussed below. Because the nature of the architecture does not specify the specifics of a system design, it is not possible to design the precise security countermeasures for ITS without a more precise implementation of that architecture. Below we only describe the types of countermeasures available to deal with the threats that have been identified.

The majority of threats to ITS come from illicit monitoring or modification of communications between the vehicle and controlling computers. These communications will probably go over radio links that could be intercepted by someone with the proper equipment. The right countermeasure, included in the architecture, is the use of encryption technology to make the transmissions into gibberish to anyone not possessing the proper cryptographic keys. Encryption always introduces a certain amount of delay into transmissions. However, ITS transmissions will all be relatively short, so that even software encryption could probably keep up with the traffic demands. If required, there are a variety of hardware encryption chips on the market that could provide increased speeds at reasonable costs, if necessary.

The use of encryption technology, however, introduces some problems. First, the use of encryption will increase the development costs, because encrypted communications are always more difficult to debug. Monitoring the communications to see what went wrong becomes more complex, because the communications all appear to be gibberish. The use of encryption could likewise make the diagnosis of equipment problems more difficult when the system is deployed.

It should also be noted that encryption technology is subject to export control under the ITAR regulations. A manufacturer of ITS equipment who wished to export that equipment outside the US or Canada would require individual export permits from the State Department. If ITS is viewed as being primarily for the US, then export controls would not be an issue.

Authentication and Non-Repudiation

Many of the threats in ITS that deal with fraud can be countered by reliable authentication and non-repudiation. The ITS architecture needs to know reliably who has requested a particular service, and it must not be possible for the requester to deny that he made a request that he in fact made. These services can be implemented through the use of smart cards and digital signatures. Smart cards are credit card-like devices that contain a significant computing and memory capability on the card itself. They are already used widely in Europe in electronic banking and in the GSM digital cellular telephone networks. The software needed to implement digital signature protocols can be implemented on a smart card at sufficiently low cost. Each user of ITS could be issued a smart card that would be inserted into a device in the vehicle to perform the necessary authentication for charging for whatever services required.

Anonymity

Some of the threats in ITS are associated with tracking the location of a particular vehicle or individual. These threats can be significantly reduced if the computers do not actually store the identity of the person or vehicle in question. Many of the services, such as electronic fare collection do not actually need to know who is making the payment. Instead, an anonymous fare card could be loaded with a certain amount of money and the fare automatically deducted at each use. Anonymous fare cards are used today in BART and the Washington, D.C. Metro. However, these fare cards are subject to attack, because they depend only on a magnetic stripe that can easily be changed by an attacker. Smart cards are much more difficult to tamper with, because the software on the card can be self-protecting.

However, it is important to note that anonymity will not solve all of the problems of tracking individual movements. Even if identities are not kept in a vehicle tracking system, an attacker can deduce who is in which vehicles, simply by recognizing patterns in traffic movements. If an anonymous vehicle always leaves from the Jones residence at a certain time and always goes to a particular work location, it is highly likely that the vehicle is driven by someone from the Jones household who works at that location. The attacker may not know with 100% assurance, but with sufficient assurance to carry out the attack.

2.2.7.2 Computer and Database Security

In addition to communications security, the ITS systems architecture specifies a number of data bases that may be subject to compromise from security breaches. Levels of trust guidelines and criteria prepared by National Computer Security Center (NCSC) can be used for the purpose of specifying data security requirements in ITS. The primary document that contains relevant information is the Department of Defense Trusted Computer System Evaluation Criteria (TCSEC), DOD 5200.28-STD, December 1985), also known as the "Orange Book." This standard defines the basic security features and assurance levels useful in evaluating the degree of trust and in specifying the requirements in procurements. There are also TCSEC "interpretations" for subsystems for different application-specific environments, including one for database management systems.

The TCSEC classifies security levels of different systems into four divisions; i.e., D, C, B, A, in the increasing order of security level. These levels are organized in a hierarchical manner such that each higher level has additional provisions (includes lower levels). The following table (Table 2.2-2) gives a summary of the different database security levels.

Table 2.2-2: Summary Features for the TCSEC Security Classes

SECURITY DIVISION	FUNCTIONS AND ATTRIBUTES
D	Provides minimal protection
C	Discretionary protection and auditing capabilities
C1	Identification and authentication of users
C2	Accountability of actions through login procedures
B	Mandatory Protection
B1	Clearance control and sensitivity labels
B2	Security labels to devices, descriptive policy model
B3	Assign user names for access to specified objects
A	Formal top-level specification and verification

The above is only a cursory description of the TCSEC security measures. The features and functions of the ITS systems and their individual security level requirements need to be examined carefully based on the NCSC's TCSEC specifications. There are considerable differences between security requirements in the context of the Department of Defense and for ITS applications. In the case of ITS, access control to prevent tampering with the system and data is more important than the need-to-know type of security of the contents of the data. Thus, the access levels may be defined in a different manner than in the case of DOD, perhaps with even a larger number of hierarchical access levels. Consequently, the requirements placed on hardware and software for different security levels will also be different. However, the NCSC's TCSEC specifications should be of valuable help in preparing the ITS security standards. The development of detailed ITS security requirements, hardware and software test methodologies, and identification of available standards should be performed subsequently to Phase II. The Table 2.2-3 gives some examples on assignment of security divisions required from the points of view of access privileges and safeguarding privacy for a set of ITS databases based on the data elements they contain. It is important to keep in mind that a security classification need not have to apply for the contents of the entire database; It could merely point to the presence of one or more data elements in the database that require adherence to the security class specified.

Table 2.2-3: Examples Of Security Level Assignments To ITS Databases

DATABASE	SEC DIV	REASONS
Information_Control_ Database	B3	This control information must be protected from external (system) access and only managed by authorized supervisory personnel. Possible security threats are (i) theft of services and (ii) influencing traffic patterns (identified in *Mission Definition* document, Appendix A)
Traffic_Information_ Archive	B3	Validity and currency of traffic reports should be protected by access controls. Possible security threats are (i) tracing vehicle or individual movements and (ii) influencing traffic patterns
Incident_Archive	B3	Misuse and unauthorized modifications should be prevented. Possible security threats is the potential for influencing traffic patterns
On_board_safety_data	C2	Information on the presence of hazmat should be protected. Threats involved: public safety
Emergency_ Response_Plans	B3	Must be protected from unauthorized access. Threats involved are (i) influencing traffic patterns and (ii) abridgment of privacy rights
Vehicle_and_driver_ safety_data	C2	Threats involved are (i) tracing vehicle and individual movements and (ii) abridgment of civil and constitutional rights
Toll_operations_ data	C2	Threats involved are (i) theft of services (ii) influencing traffic patterns
Demand_Archive	C2	Threats involved are (i) theft of services (ii) influencing traffic patterns
Traffic_Control_ Archive	B3	Threats involved is the possibility of influencing traffic patterns
Roadway_Condition_ Archive	C2	Threats involved is the possibility of influencing traffic patterns
Map_Database	C2	Threats involved is the possibility of influencing traffic patterns
Ride_Share_Data	B3	Includes personal information which must be protected to preserve privacy. Threats involved are (i) tracing vehicle and individual movements and (ii) abridgment of civil and constitutional rights

2.2.8 Map update

For many of the market packages in the National Architecture, a periodic map update is required in which the user receives an update to a map database through some kind of electronic means. The users in this case include both the traveler, at a traveler locale or in their vehicle, or some service provider, generally referred to as part of the infrastructure.

As was stated in Section 2.2, many map data bases are now available, and can be used by service providers (e.g., management and/or dispatch centers) as their basic roadway map information. Similarly, the user may have an on-board map data base residing in a CD-ROM (in general region/city specific). Starting from a map data base, the service provider needs to ensure that the required up-to-date information pertaining to the roadways of interest is incorporated into the map data base. This information depends on the services offered; for example, it could consist of temporary road closures and detours resulting from incidents or scheduled events, traffic directions (not normally in such map data bases), or even congestion information in the case of traveler information. The architecture, thus, must accommodate these information update needs, as well as the transfer over the air, on request, of map-related information to the users.

Within the National Architecture, map updates are generally provided to the public and to associated institutions using traditional electronic means of a storage device (e.g., a CD-ROM) carrying the updated map information. If map updates are relatively minor, these updates can be made on an exception basis, where the data that is updated is only the (minor) changes in the database. This approach to exception reporting could also be conducted over wireline (e.g., dialup) services or (at considerable expense and data load) over the wireless network. Note here that the Joint Team does not advocate the transfer over the air of maps, given the associated high costs and impact on the communication system (except perhaps for very minor exception updating).

In all cases, the map database updates over wireline (or wireless) would be conducted during off-peak periods. Again, this off-peak update is necessary because of the potentially large amount of data that must be updated over this communication link (e.g., tens of megabytes of data). Also, the periodic (and/or cyclical) frequency of these updates would suggest considerable congestion in the wireline or wireless system around the time of the update: perhaps several hundred users would be interested in an update for a given urban map data base. Again, both cost and data loading factors push the operations of map updates to off-peak periods.

For this reason, the map update function was not included in the communications simulation modeling, as it focused only on peak period communications system usage (which was assumed not to include map updates). Additional investigation of these assumptions is described in the *Communications Analysis* document.

2.2.9 System reliability and maintainability

As part of the evaluation of the Phase I architectures, we undertook a preliminary hazard analysis to examine the reliability and the robustness of the architecture most generally. This hazard analysis of the 29 user services defined by the FHWA is summarized below as they relate to the criteria of reliability and maintainability. Criterion 2.2, discussed in Section 2.2.10, addresses the architecture operation and performance in degraded modes.

For the criterion of reliability and maintainability, we are concerned that there may be hazards within the architecture that may lead to unreliable service or system performance. There are many places in the systems architecture where a hazard is in principle possible but where the risk will in practice be reduced to an acceptable level by good design. These hazards generally seem to occur in the services where more significant and centralized system management are possible: the traffic management market packages, as well as the vehicle safety systems (AVSS) market packages.

The conclusions of the preliminary hazard analysis suggests that the faults of reliability and maintainability are not functions of the architecture itself, but rather are functions of the design, production, and operation of the related products and services. Thus, the operational reliability of the architecture is more a function of a candidate architecture deployment than a feature of the architecture directly.

2.2.10 System safety and availability in degraded mode

Part of the evaluation of the National Systems Architecture is to investigate the question of how an architecture implementation may accommodate degradations in service, for whatever reason. If degraded-mode operation means that some service cannot be provided via ITS, and it is important to life or property, it is a matter for consideration as to whether the current way of meeting the problem needs to be preserved using redundant systems or other forms of back-up. If this is not done, loss of service will result in greater delay, and so greater loss than now exists. Such "graceful decay" and other "redundancy" properties are essential for the planning and integrity of the design of ITS products and services.

In degraded service modes, there is not only the degradation of service but also the increase in the potential for false information to reach the end user. Architectures may differ quantitatively in their liability to operation in degraded modes of passage of meaningless or false messages. This will affect the risks of losses in the services which are sensitive to information contained in these messages; or alternatively affect the required reliability of the service equipment. In none of the services we have been able to examine thoroughly in the preliminary hazard analysis has the form of the architecture made a qualitative difference in the passing of false or meaningless information during degraded modes of operation. However, the preliminary hazard analysis has identified several hazards relating to graceful decay and system redundancy and security that we believe are important to our architecture development, including:

1. The risks of serious technical hazards with several of the advanced vehicle safety systems market packages (e.g., automated highway systems, intersection collision avoidance, etc.). These were also identified as critical risks in the *Feasibility Study (Risk Analysis)* document. This includes the ability of the architecture's functions to degrade gracefully and safely with these market packages

2. The need for good design of major systems (e.g., traffic management and signal control functions).

3. The need for security and integrity in transmitted messages within the architecture.

The Joint Team architecture incorporates reasonable mitigation approaches to these issues. In response to the first item, the preliminary architecture definition for the AVSS market bundle emphasizes vehicle-based functionality, and thus minimizes the need for critical external interfaces. Additional research in the AVSS area is continuing outside of this national ITS architecture development effort (i.e., through ongoing NHTSA work, the national AHS consortium, etc.).

As for the second point, the critical systems design issues are based on potential deployments of the architecture. To this end, we have included important design criteria in our development of the architecture's evaluatory design. Details on this process are included in the *Physical Architecture* document. Finally, the Joint Team's approach to information integrity and security address the criticality of communications links. The analysis of these issues, and the treatment of security and integrity issues, is described in Section 2.2.7, describing the technical performance of our architecture with respect to security safeguards.

Chapter 3
Framework for Benefits Analysis

3.1 Benefits Evaluation Objectives

The benefits of ITS user services have been discussed for a number of years, but in general these discussions have ignored the underlying architecture behind the implementation of these user services. These projections of benefits are in some ways short-sighted in that they have not explicitly considered the benefits of a particular architecture, or how that architecture might explicitly impact the level of benefits. Clearly, the whole systems architecture development project is based on the premise that the chosen architecture will have implications for the implementation of the 29 user services suggested by the FHWA. In the benefits analysis, the objective is to determine what elements of the national architecture will positively impact ITS deployments and what level of benefits might be achieved through implementation of the national architecture.

The national architecture *per se* serves a number of important objectives for ITS deployments. The results of the technical performance analysis in Chapter 2 suggest that the architecture does provide some support for ITS implementations. In the benefits analysis, a first objective is to identify benefits that are derived from having a national architecture. In this respect, the analysis examines likely products from the national architecture program and how these may be used productively to impact ITS standards development and systems design and deployment.

The Joint Team has also prepared an analysis of the transportation system benefits of ITS. This was done based on the prevailing belief that a single source of ITS benefits could be beneficial in understanding the value of ITS more generally. In this regard, the *Mission Definition* document submitted separately by the Joint Team presents a number of goals for Intelligent Transportation Systems, including:

1. Improve operational efficiency and capacity
2. Enhance mobility and the convenience and comfort of travel
3. Improve safety
4. Reduce energy consumption and environmental costs
5. Increase the economic productivity of individuals, organizations, and the economy as a whole
6. Create an environment in which the development and deployment of ITS can flourish

These system benefits may be addressed at the level of the individual, improving travel times or reduce uncertainty about travel options, and at the level of society as a whole, improving the economy by providing more jobs or improving the air quality in metropolitan areas across the country.

The benefits of an ITS implementation depend on a number of factors, as indicated in Figure 3.1.1. In the figure, the shadow boxes represent specific outputs of the architecture development program: the standards development plan, standards requirements, and the implementation strategy. The standards development plan identifies critical subsystem interfaces in the architecture and results in recommendations for required interface standards based on the message sets in the physical architecture. In addition, the architecture is accompanied by an implementation strategy, making recommendations on strategic policies, management options, and investment decisions related to both the architecture and to its deployment through ITS market packages.

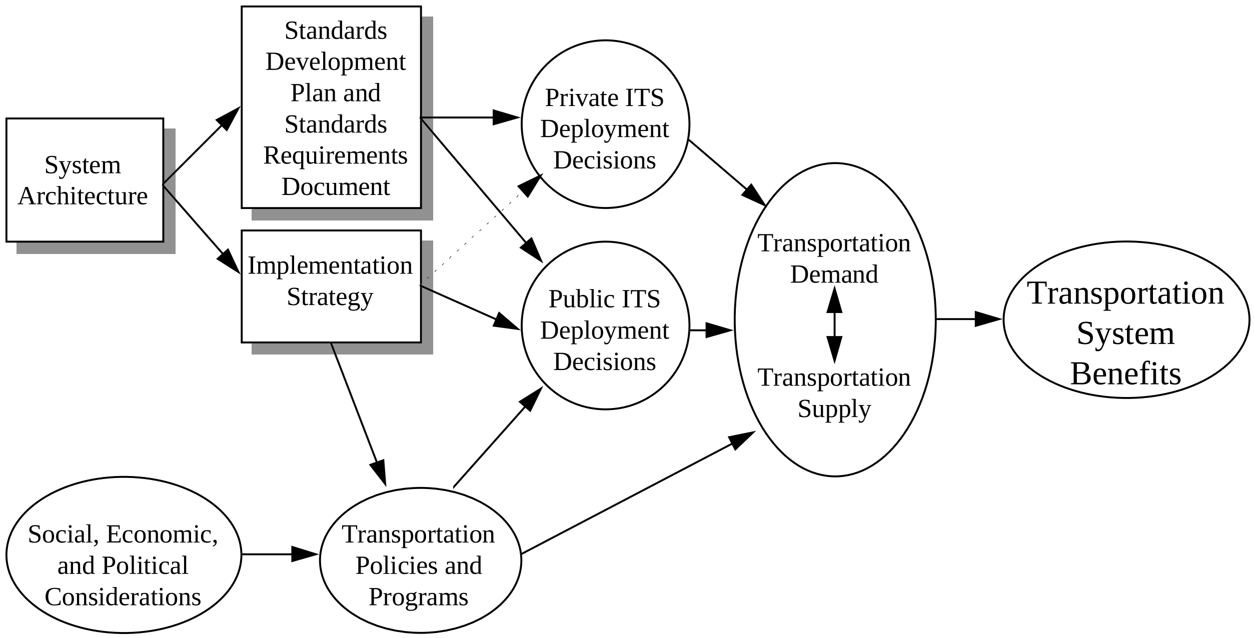

Figure 3.1-1. The Relationship of the ITS System Architecture to the Benefits

The implementation of particular ITS services, beneath the framework of the system architecture, must also be incorporated within the existing transportation planning process. Factors influencing and affecting these larger transportation planning objectives are shown in Figure 3.1-1 as ovals. Transportation policies and programs are shaped by broad social, economic, and political considerations. The development and deployment of ITS, as suggested through the implementation strategy, will ultimately need to be integrated within this larger transportation planning process. Thus, the ultimate deployment of the architecture will be a result of both the physical architecture itself and its implementation plan, but also with consideration for a broader set of transportation goals, policies and programs. The private sector, as a key participant in producing ITS products and services, may also respond to the recommendations of the national architecture.

Taken as a whole, the implementation of ITS market packages, and thus the ultimate level of benefits achieved by that implementation, depend on both the architecture and the extent to which broader transportation policies and programs support the deployment of these packages. These supporting policies and programs influence the current and future market penetration levels of the market packages which, in turn, effect the level of benefits achieved as a result of implementation.

3.2 Benefits Analysis Scope

The point of the benefits summary, most directly, is to identify the type of benefits provided by a national ITS systems architecture. Of perhaps equal importance in the team's development of an architecture is the identification of critical connections between aspects of the architecture and these benefits, as well as the possible equity of benefits as they accrue to different segments of society. This section (3.2) addresses the types of benefits evaluated in this study, while the following section (3.3) discusses the connection of the architecture to benefits as well as the allocation of benefits to different segments of society.

For the purposes of this study, the benefits of an ITS architecture in each of these areas may be evaluated using primarily qualitative techniques. The benefits of the architecture in fostering a successful market for ITS products and services revolve around three main areas: 1) the value of standards to enhance inter-operability and product economies of scale; 2) the value of integrated information systems for improved system management; and, 3) the value of technologies that can be used simultaneously for a number of different ITS functions. These issues are addresses in the following chapter (Chapter 4).

At the same time, the deployment of ITS market packages may provide a broad set of benefits to both individuals and the transportation system as a whole, including reducing congestion, improving air quality, and reducing energy usage. Improvements in travel safety and increased economic productivity contain other measures of benefits, and thus require a somewhat different analysis approach. Improvements in traveler mobility and other aspects of quality of life rely entirely on qualitative discussion of the types of benefits that may be expected. These benefits are described in greater detail in Chapter 5.

3.3 Analysis Methods

Two specific evaluation tasks have thus been described above. First, the benefits to be realized from the development and adoption of the national ITS architecture must be discussed. The evaluation of the benefits of an architecture *per se* can be addressed at three different levels, as described below.

3.3.1 Architecture Benefits

National, open interface standards. The development and adoption of open interface standards for ITS will have significant impacts on how a market for ITS products and services develop. These architecture-related standards may be motivated for any number of reasons, including:

- Desire for national or regional inter-operability of products and services
- Encouragement of open markets for ITS products
- Economies of scale in production or purchase
- Encouragement of evolutionary development and deployment of new technologies

With such standards in place, users will benefit from the ability to “plug and play” different components into a larger ITS system. At the same time, the existence of nation-wide or even regional standards implies that products and services may operate over a wide geographic area, eliminating comparable products that may not be entirely compatible with specific system designs. Price competition, and wide geographic markets, may reduce the associated costs of ITS products and services. On the opposite side, standards may inhibit technical innovation, or at least may restrict technical innovations within a particular ITS service.

It must be emphasized that it can be difficult to forecast accurately the impacts of standards. For some standards, such a forecast may require us to predict *the evolution of technology and markets*, both with and without the standards in place. Any technology and market forecasting is difficult to perform with any degree of accuracy: the evolution of technology is highly "path dependent", and path dependencies are compounded by the system and network nature of ITS. Competing and complementary technologies evolve in unpredictable ways, and in turn interact with unpredictable markets. The evolutionary results may depend strongly on local "accidents" along the way, events or combination of events that are difficult to anticipate. This character of path dependency, and the notorious lack of success that prognosticators have had in the past in such situations, is well documented with many examples over the past century and a half, starting with the telegraph, telephone, and electrical generation and distribution, and continuing through radio, television and into the contemporary "information revolution," with its web of computers and communication technologies.

It is also true, however, that the difficulty of such forecasting will depend very much on the particular standard in question. Many of the ITS standards identified in the National Systems Architecture, dealing as they often do with communication interface requirements, may not have profound impacts on core technologies, and thus some of the complicating effects alluded to above may not be present for these standards.

A complete analysis would have to describe the impact of standards directly on the particular market packages governed by the standard (and each will tend to have its own specific effects that need to be identified) and then trace these through to indirect "system" effects. We try to identify some important "system" effects, but warn the reader that this dimension will be inevitably incomplete at this point because of the complex interconnections in ITS.

Another important note of caution is that the benefits in each category do not necessarily add for each user, nor do the benefits to each user group simply add to each other to get total benefits. It was not the purpose here to outline how an aggregate net benefit assessment could be performed. Such an analysis would have to set up a framework that avoided double (or triple) counting by carefully assessing the transactions among the three groups defined here, and framing an overall assessment within this framework. This is not possible in the course of the remaining time in the Architecture program. Rather, the main purpose is to provide some framework for discussion on methods to assess the merits of ITS- and architecture-related standards.

The qualitative evaluation of open ITS interface standards that is presented in Section 4.2, then, reviews arguments regarding:

- Benefits of product inter-operability, both over geography and over time;
- Possible economies of scale in production, distribution and use of ITS products and services;
- Possible changes in the rate of technology development and innovation, as well as changes in choices of technology in the marketplace.

In addition, the impacts of standards will differ significantly based on the side of market; i.e. whether one is an end user or a service or technology provider. For each of these types of standards "users," the likely benefits and disbenefits are described with respect to the type of primary effect, e.g. interoperability, cost reduction, and technology choices.

Systems Integration. The national ITS architecture also is a comprehensive framework for an ITS system. As such, the architecture identifies management systems that may benefit from sharing information on transportation system performance and system needs. In doing so, better operational and management decisions may ensue. Section 4.3 reviews where such integration is possible within the national architecture framework, and describes what likely benefits may accrue in this integration.

Technology Synergies. One of the other advantages of having a comprehensive national architecture is that the architecture identifies similar types of data flows, functions and interfaces across the full spectrum of ITS user services. Because of this broad view of ITS, the architecture allows one to identify specific functions and interfaces that may use similar information processing and communications technologies. In many cases, such synergies may allow long-term reductions in the cost of supplying ITS products and services. Section 4.3 suggests where benefits (in the form of cost savings) may be realized by using these common technologies.

3.3.2 ITS-related Benefits

Second, the benefits of specific ITS market packages may also be identified, together with the logical connection of these benefits to the ITS goals stated above. To evaluate the benefits of ITS, a tool called a "benefits flow diagram" is used to show in detail the logical dependencies between ITS market packages, and transportation system performance metrics, and the ITS goals. Based on these diagrams, the following five steps were identified:

1. *Specification of the elements of the architecture which impact the benefits of the system and the market packages which reflect these elements.* This has already been suggested by the analysis of architecture benefits (to appear in Chapter 4).

2. *Identification of ITS goals and benefits.* This has already been described, and is highlighted in the Joint Team's Mission Definition document.

3. *Identification of benefits metrics.* The appropriate metrics for measuring transportation system benefits are described in more detail in Section 5.1.

4. *Identification of logical dependencies from market packages to benefits metrics*. Benefits flow diagrams highlight these dependencies between market packages and specific quantitative metrics.

5. *Identification of logical dependencies from benefits metrics to ITS goals*. These logical connections are also described in the diagrams, between specific metrics and the goals mentioned above.

The importance of this process is to identify what types of benefits an architecture might provide, how those benefits might be traced to market packages deployed from that architecture, and the equity of those benefits when compared with costs among different groups in society.

Ultimately, a number of different benefits metrics are addressed in this analysis. Specific quantitative and qualitative metrics are developed in Section 5.1, grouped roughly in accordance with the six ITS goals described above. Complementing this analysis, the benefits flow diagrams are used as a basis for suggesting qualitative benefits of specific market packages. This analysis is described in Section 5.2.

Chapter 4
Benefits of the National ITS Architecture

This chapter describes an assessment of the National ITS Architecture in providing ITS benefits. However, rather than discussing the benefits of ITS more generally, this section focuses on the possible benefits of the national architecture itself. Of course, the architecture itself has no implicit value independently from specific ITS system designs that are based on the architecture. The analysis described in this chapter explains the advantages of the national architecture in developing and integrating these system designs. Separately, Chapter 5 describes the transportation system benefits of ITS and specific market packages.

The national architecture provides a fundamental building block to assist the public sector, private sector and individual consumers in developing, designing, and purchasing specific ITS products and services. The architecture, by its nature, forms a framework by which specific ITS system designs can be developed. As presented in Chapter 2, the national architecture has desirable system performance characteristics: comprehensive support for ITS services, inter-operability of components, open interfaces, flexibility in local ITS system design, and support for both the near-term and long-term evolution of ITS. It is precisely these technical features of the architecture that in turn suggest the specific benefits of the national architecture.

In describing the benefits of the national architecture, the primary motivation has been to address these benefits in the context of ITS systems integration. Because the national architecture represents a comprehensive treatment of ITS most broadly, systems integration lies at the very heart of the architecture development effort. Section 4.1 presents a broad overview of the types of system integration and the nature of these benefits. Two salient aspects of system integration that are called out in the national ITS architecture program include:

1) Recommendations for standards and a standards development plan; and,

2) Synergy in managing data sharing needs, functional coordination, and common technologies.

In these two areas, more specific benefits from the national architecture can be identified and analyzed. Each of these areas is developed in subsequent sections (4.2 and 4.3, respectively) in this chapter.

4.1 Benefits of Systems Integration

The benefit of a national systems architecture can be described most clearly using the concept of systems integration. Systems integration is conventionally recognized as the process through which a number of products and services, both hardware and software, are specified and assembled into a complete system that will achieve the intended functionality. In this section, the analysis of systems integration achieved through the national ITS architecture delineates benefits at both the architecture and deployment levels.

Table 4.1-1 depicts the benefits of system integration at two levels of engineering and design. At the architecture level, the engineering tasks are predominantly top-down, starting with stakeholder needs, product and service concepts, and functional specifications, and working down to logical and physical architecture development. At this level the engineers design the system, subsystems, functions, and interfaces required to deliver the selected user services. System integration at the architecture level focuses on functional and logical inter-connectivity among subsystems and semantic consistency. This has been the primary focus of the national ITS architecture program to date.

Table 4.1-1. Benefits of System Integration

ITS Engineering and Design Levels	Types of System Integration	Benefits of Integration
National ITS Architecture • Subsystems • Functions • Subsystem interfaces and data flows • User services	• Functional • Semantic	• Functional inter-operability • Open system standards and semantic compatibility
Local / Regional Deployment • Technology • Products and services • Market packages • Local needs	• Technology interfaces • Product and service interfaces • User interfaces • Inter-jurisdictional interfaces	• Inter-operability of components and market packages • Synergistic deployment • Inter-jurisdictional compatibility of data sharing

However, when it comes to local and regional deployment the designers engage in systems integration in the more conventional sense of the phrase. The task of the systems engineer in this case is to assemble hardware, software, data base, and model base packages, using the existing national architecture and its related standards, to meet the immediate and long term needs of the community. Integration technologies like data transfer protocols, database structures, and document protocols assist the engineer in the system integration process. The goal is to meet the local requirements through providing bundles of services in the most cost-effective and efficient manner. The most effective integrated system is often the most usable system that accounts for: (1) compatibility among system components; (2) data sharing among jurisdictions; and, (3) synergy among market packages. The remainder of this section will delineate the six types of system integration at the architecture and deployment levels (listed in Table 4.1-1), and the specific benefits expected from system integration through the process of architecture design and implementation.

4.1.1 Architecture Integration

There are two types of system integration at the architecture level: (1) functional, and (2) semantic. It is through the process of architecture development and system integration at the architecture level that functional inter-operability, semantic compatibility, and open system standards guidelines are provided.

1. **Functional Integration.** Functional integration is the process where functions are allocated to identified subsystems and interconnected through data sharing interfaces. Important considerations include (1) the location where services are to be performed, (2) the location of data fusion and analysis, (3) the sharing of identical or similar functions among services, and (4) the most cost-effective modes of data sharing among the sites. This issue of functional integration is discussed at more length in Section 4.3, examining synergy that occurs in the national architecture in the performance of functions and in data sharing.

2. **Semantic (or Data) Integration.** It becomes quite difficult to integrate existing subsystems if concepts are defined slightly differently among the subsystems, or when identical concepts are named differently in each of the subsystems. Semantic integration insures either that the same concepts mean the same thing in different portions of the system or that there exists a translation mechanism that will resolve semantic inconsistencies so as to allow information exchange across subsystems. Semantic inconsistencies generally exist when different subsystems are procured from different vendors. Inter-connectivity can be enhanced if the vendors build to the architecture by taking into account conventions or standards for naming and defining data, parameters, processes, files, documents, and all the other elements that may be transferred or referenced across the systems. Much of the architecture process was devoted to defining and labeling systems, subsystems, functions, data flows, and process specifications (P-specs). These definitions provide semantic consistency throughout the architecture, and if used in the implementation of the architecture, will facilitate the integration of services and market packages.

4.1.2 Deployment Integration

System integrators often initiate a system design from scratch, that is, without a universally agreed-upon architecture for allocating functions to subsystems, defining subsystem interfaces, and providing consistent definitions and labels to the things that make up the system. The problem with this in ITS is that system architectures for different cities or agencies may be formulated differently on different projects by different contractors. The contractors are required to assemble system components that may be inherently incompatible both functionally and semantically. The challenge in this case is to find the best technologies to translate the data and to link the components together. As a result, the integration effort focuses on integration technologies that support the transfer of data among subsystems, including transfer protocols, document protocols, and remote procedure protocols. The selection of these technologies becomes the defining aspect of the architecture, and often leaves the contractor, and the eventual owner, with a closed system based on proprietary components and integration technologies.

The national system architecture should provide a more secure foundation for the integration process through functional integration of subsystems and data transfer conventions, through semantic consistency, and through recommendations for open system standards. With the national architecture, supported by the USDOT, and with related standards supported by formal standardization bodies, the job of the system integrator at the local/regional deployment level becomes less onerous, much more well defined, and much more efficient. The engineering contractor may select components from a number of competing vendors that meet common specifications. Furthermore, the contracting organization can more easily and accurately specify the services and products for procurement. In this case the systems integration contractor then becomes more of a component assembler than a systems architect. Benefits of the national architecture in these areas are highlighted below.

1. **Integration Technology.** This is the glue that binds a system together. Even with the subsystems, functions, and data flows defined it is necessary to develop or adopt technologies to support the transfer of data across different subsystems. Data transfer includes file transfer protocols, document protocols, and remote procedure calls. At the technology level integration is accomplished through automatic data transfer, common database structures, and process-to-process communications through well-defined functional interfaces. The national architecture should limit the variation in the integration technologies and even promote some standardization. This level of definition at the interfaces should increase the potential for inter-operability of subsystem components and the integration of market packages in an evolutionary development path. It will also lower system acquisition and integration costs.

2. **Product and Service Integration.** Some products offer inherent integration opportunities. For example, the map-based guidance system also typically provides vehicle location services as part of the package. Most of the traveler information systems require some form of traffic monitoring and surveillance that may also be required for signal control or freeway management. In some cases the services may have a subsystem or function in common. For example, ramp metering and on freeway entrance ramps and freeway incident detection both require traffic detection. Deploying ramp metering and incident detection on the same stretch of freeway can produce synergy where the traffic detectors can be used by both systems. Furthermore, ramp metering may reduce downstream incidents so the net benefits from combined deployment is greater than the sum of the separate deployment of the services. The system integrator needs to be aware of the synergistic potential in deploying the products and services, and take this into account in preparing the overall system design and evolutionary deployment plan.

3. **User Integration.** The users of the systems want the integration to be seamless so they can concentrate on their tasks and not the specifics of the technologies or the user interfaces. Successful user integration generally requires easy access to different applications and systems, uniform user interfaces, consistent data, and consistent use of semantic concepts. This level of integration is not defined by the architecture and any standardization is likely to emerge competitively, and resulting in informal conventions and standards.

4. **Inter-jurisdictional Coordination/Integration.** It is quite common in any region of the country to find the local transportation agencies operating quite independently. This is sensible in many respects because much of the transportation infrastructure is funded locally to serve the needs of local residents. This type of independence is expected in local governance. However, local independence may also produce traffic inefficiencies and paradoxical traffic behavior. The lack of traffic signal coordination in contiguous

jurisdictions is often cited as an example. Lack of coordination between state and local jurisdictions is also quite common. ITS promises to help resolve some of these issues by providing the tools to improve data sharing and the levels of coordination among jurisdictions, should the institutional mechanisms also fall into place. A common architecture adopted across jurisdictions will facilitate the sharing of data among the agencies and service providers.

4.2 Benefits of Standards

One of the assumed keys to deployment integration is the development of product and interface standards for ITS. It has been presumed throughout the architecture development program that one of the primary benefits of the national system architecture is to identify key areas for ITS standards and to propose the requirements for such standards. Indeed, this is one of the fundamental reasons behind the need for the *Standards Development Plan*, *Standards Requirements*, and, in part, the *Implementation Strategy* documents. The analysis presented in this section attempts to articulate, in a common location in the architecture documentation, the primary motivations and potential impacts of ITS standards. In this way, the benefits of the national ITS architecture from the perspective of interface standards can be understood.

Underlying the discussion of standards is the basic question of why standards are needed in ITS. At this point, it is perhaps useful to identify some basic assumptions underlying this analysis:

- It is one of the main goals of the national architecture program to deliver an architecture, and associated standards, that enhance the development and long-term sustain-ability of an ITS market.

- End users desire to purchase and use ITS products and services at the least possible cost and with the maximum amount of compatibility of such products and services with other ITS systems and components.

- In order to develop and maintain a viable market, ITS product and service vendors must make a reasonable return on investment.

These assumptions are important, primarily because it is recognized that the goal of the national architecture must trade off the needs of both users and of vendors. Inasmuch as users and vendors have competing goals, industry-wide consensus on ITS standards may be difficult to achieve.

At the same time, it must be acknowledged that consensus standards are not the only possible solution to the objectives of the architecture program most specifically and of users and vendors more generally. At least four alternative approaches exist for managing ITS interfaces:

1) *Acceptable solutions from the status quo*: Existing low levels of compatibility, proprietary products and services, and gateway technologies (translators or adapters) to improve inter-connection of components.

2) *De facto standards*: Standards developed from government regulations, existing proprietary systems or “common practice” among coalitions of end users.

3) *Formal standards*: Competing or somewhat ambiguous standards that emerge from formal standards development efforts.

4) *Unambiguous, uncontested (i.e. industry-wide consensus) standards*.

Much of the analysis that follows centers on the benefits and impacts of the last (and assumed preferred) option: industry consensus standards. However, one must keep in mind these other alternatives when identifying the likely benefits (and possible disbenefits) of these consensus standards.

Furthermore, this discussion differentiates the benefits of standards, and of standardization most generally, into two categories. In the first section describes the benefits and other impacts of standards, once such standards have been established. This provides a fundamental set of factors that influence the development and long-term adoption and use of consensus standards. Based on these factors, the second section describes some of the motivations, benefits and impacts of participation in the standards development process, for the government, ITS vendors and end users. In particular, understanding vendor and user motives in this process may assist the federal government in providing appropriate guidance and support to ITS standards development.

With these important issues in mind, the analysis below is organized as follows. Section 4.2.1 describes the benefits and possible disbenefits of ITS standards, once such standards have been developed. These benefits and disbenefits are described from the perspective of both the end user (Section 4.2.1.1) and ITS product and service vendors (Section 4.2.1.2). In addition, the possible benefits and disbenefits to users (Section 4.2.2.1) and vendors (Section 4.2.2.2) in participating in the standards development process. In this way, this section identifies possible benefits of the national architecture in developing industry consensus standards for ITS.

4.2.1 Consensus ITS Standards

4.2.1.1 User benefits and disbenefits

To begin, there are significant benefits and possible disbenefits for end users in having ITS standards. For the end user, benefits of standards that are widely cited in the realm of information technology include:

1) Portability: With a set of standard interfaces, ITS components, hardware, software and other services may have "plug and play" capabilities. In this way, products and services can be moved easily between specific operating platforms, communications media, or from one system (e.g. a vehicle) to another.

2) Inter-operability: The standard set of ITS interfaces allows products and services to operate in conjunction with other products and services. The national architecture specifies the inter-connections between subsystems, allowing a wide variety of equipment and market packages to operate in conjunction with other ITS equipment packages.

3) Data exchange: In the same way that interface standards achieve inter-operability, they also allow exchange of important data between different ITS services. The value of this data is enhanced by having either "standard" data definitions between applications or standard interfaces that allow unambiguous translation of data from one application to another.

4) Expanded choice of products: By defining an interface, product and service vendors can focus on supplying components that meet these interfaces, without spending too much effort worrying if their components will be compatible with other vendor's products (i.e. without worrying about inter-operability). Since more effort can be spent on product development rather than product compatibility, a larger choice of products is likely to ensue. Thus, vendors can satisfy a wide variety of end user tastes and variations.

5) Economies of scale: Standards allow certain economies of scale in production of products and services in the market as a whole. In general, such lower costs of production across vendors will lead to lower costs to consumers.

6) Network externalities: In addition to the economies of scale, there is the added effect that a larger user base (i.e. a larger network of users) will lead to direct increases in benefits. The network externalities occur when a larger pool of users increases the level of service to each individual user. The Internet and the telephone system are particularly obvious examples where more users implies higher service for each user (i.e. more access for each existing user). Examples in ITS more specifically include: route guidance (more users of optimal routing improves each driver's travel time); dynamic ride-sharing (a larger pool of users increases the likelihood of a shared ride); yellow pages and reservation (the more participants, the better information for travelers); and so on.

7) Shorter learning curve: In the long run, standard product features and interfaces have the added advantage that less time is required to train personnel how to use a particular product or service, since it is likely to have common features with other products that people already know.

At the same time, the types of benefits of standards mentioned above may also lead to particular undesirable impacts for users. In particular, for the end user, the existence of ITS interface standards may lead to problems in terms of costs, technology compatibility, and long-term technology innovation:

1) Short-term cost implications: Users who are early adopters of standards may, by the nature of a developing market for standards-compatible products, pay considerable costs for "standardized" products and services. The magnitude of costs for these early adopters can be substantial. In many cases, the initial price of a standardized product may be significantly higher than other (e.g. proprietary) existing systems. Also, if a market does not fully materialize, these early adopters may then have to deal with high costs of operating and maintaining the product.

2) Long-term costs of technology: The standards-setting process can lead to a choice of technology that is, in the longer term, inferior to other existing or emerging technologies. This may directly influence the long-term costs of purchasing, operating and maintaining the specific ITS products and services. That is, one may argue that the costs associated with alternate technologies may be lower that those associated with a standard. This effect is further compounded by the slowing of technology innovation that often results from consensus standards.

3) Long-term compatibility and product life cycles: Adoption of a particular ITS standard does not necessarily imply that products will be compatible in the long run. First, if the standard is not universally adopted and applied, those early adopters may be "orphaned," with resulting high costs of operating, maintaining, and ultimately replacing the obsolete product. Second, given the rapid rate of innovation in information technologies, the life cycle of a particular product or service may considerably outlast the value of the standard. That is, the longer-term cost savings and compatibility may not be realized if the standard is obsolete before the technology needs to be upgraded or replaced. As an example, the rapidly expanding market for analog cellular communications, which has a standard, is now moving rapidly toward digital cellular.

4.2.1.2 Vendor benefits and disbenefits

The adoption of industry consensus standards may lead to benefits for some ITS product and service vendors and clear penalties for others. Specific benefits that are likely to accrue to all vendors include:

1) Ignition of markets: In many cases, the existence of an industry-wide standard may be a key element in initiating a market. That is, the existence of a standard allows significant economies of scale in production, bringing prices down sufficiently to have a market "take off." Having a standard may allow the development of a market where virtually no market existed before. Examples from the field of information technology include analog cellular phones, the Internet, and digital photography.

2) Expanded markets: In addition to igniting new markets, the system compatibility that results from consensus standards may lead to market expansion. A diverse and expanded choice of products for a particular market may be developed, as vendors take advantage of variations in user needs and tastes.

3) Technology insertion: The specification of ITS interface standards means that new or innovative technologies that are compatible with the interface may be introduced. In this way, new technology innovation may be stimulated. So, while standards may limit technology innovation on any one interface, they also may significantly enhance innovation for compatible products and services.

At the same time, standards may also have significant impacts on vendors and on the ITS industry as a whole, including:

1) Market profitability: Open standards typically lead to significantly greater price competition for compatible products. Profit margins for vendors with proprietary or off-the-shelf integrated solutions are thus likely to decrease. At the same time, price competition has obvious benefits for end users.

2) Technology innovation: Standards often inhibit innovation for technologies that are defined within the standard. That is, they “lock in” particular technologies, and such choices are often difficult to change. In addition, they may eliminate other cost-effective or technically superior options (e.g. other emerging technologies, gateways, etc.).

3) Common vendor “playing field”: In general, interface standards allow a wider variety of products and services to be offered, leading to a “level playing field” between both large and small vendors. In addition, as interface standards are adopted, the need for vertical integration of businesses to provide products and services decreases. These market forces may yield greater economic productivity from vendors, and cost savings to the end users.

4.2.2 The Process of Standards Development

The discussion above gives some of the underlying motivations for both end users and vendors to participate in the process of developing standards for ITS. There are also several factors about the standards development process itself that contribute to the ultimate benefit of the standard: the timing, the scope, and the nature of government involvement.

First, the timing of the standard has significant impact on its potential benefits. Under ideal circumstances, a standard should precede strong growth in a particular ITS market, and should leverage existing and well-proven technology. From one perspective, it is far easier to reach consensus about possible standards before vendors have a significant investment in a product (i.e. before a large market exists). Once the market develops, the task of developing universal consensus standards may be opposed by those vendors or users facing significant losses if a standard is adopted. On the other hand, it is generally favorable to begin standards development by leveraging existing and mature technology. With immature technology, the standard may be constructed from a technology that is technically and/or economically inferior.

Second, the scope of the standards development efforts will affect the ultimate benefit of the standard. Consensus standards require the input of a broad range of end users and vendors. An ideal standard is one that is large enough in scope to provide significant improvements in product compatibility among the user community, but small enough in scope to minimize the impact on existing or potential vendor solutions. When a balance between these interests can be found, the standard faces broad acceptance from both users and vendors. If the scope is too broad, user needs will be satisfied with the standard but vendors will be unwilling to produce products matching the standard. If the scope is too narrow, users will see no improvement in product compatibility. Striking such a balance, therefore, can significantly improve the acceptance of the standard.

A third area of concern, particularly for ITS standards that may emerge from the national architecture program, is the extent to which the government (at all levels) should be involved. Concerns have been raised that the government may act as a “blind giant” in developing ITS standards: they may provide considerable effort and direction, but are likely to be much less informed about standards requirements than the vendors and end users. At the same time, government support for standards development may speed up the process and ensure the end result is favorable for all involved.

Possible reasons for government involvement in standards development could include:

1) Anticipated government purchases of products or services related to the standard

2) Need for government regulation and spectrum allocation for particular services associated with the standard

3) The promotion of standards in the “public interest”

4) An element of long-term (national) industrial strategy

Any or all of these motivations may come into play for ITS standards. The key seems to be balancing these governmental motivations with the particular needs and desires of users and vendors. These areas are discussed below.

4.2.2.1 User benefits and disbenefits

To those users who actually participate in the standards development efforts, the following benefits can occur:

1) Competitive edge: Users who are aware of the likely outcomes of the standards development process may have some competitive edge over other users. Such benefits may occur naturally due to: 1) Earlier recognition of the ultimate result (i.e. the standard), and thus earlier planning and purchase of compatible products; and, 2) participation with vendors in the standards development process may lead to more favorable business relationships later.

2) Evolution and compatibility: In addition to the competitive edge cited above, users may also ensure that their existing systems and/or current purchases will be accommodated in the standard. As the consensus process works, the user's current system may either: 1) directly affect the specification of the standard; or 2) be accommodated through some form of backward-compatibility that is written into the standard.

On the disbenefits side, participation and buy-in to certain standards efforts may result in costs directly to the user:

1) Direct costs of participation: Users suffer the direct costs of participating in the standards development process. Often, this involves dedicating well-qualified experts to the development effort, at considerable opportunity cost to the expert (and to their employer).

2) Angry orphan: The risks that a standard will result in little or no cost savings, or no improvement in technology, can result in considerable cost to those users who contributed most to the development of a standard. Considerable costs, in terms of personal and corporate investment in the standard, are often required as part of the standards development effort. The volatility of the success of standards may lead to significant personal and corporate losses.

3) Time to market: Unambiguous consensus standards take considerably longer to develop than many alternatives (e.g. the status quo, production of gateways/adapters, and development of multiple competing standards). The risk here is that the delay in developing a consensus standard may have adverse impacts on an existing or emerging market. End user needs may change significantly by the time the standard is produced.

4.2.2.2 Vendor benefits and disbenefits

Vendors who provide ITS products and services will participate if they are convinced that the end result of the development efforts will be financially beneficial to their firms. Particular benefits to vendors to participate in standards development include:

1) Market initiation and enhancement: One element of vendor participation is the belief that the standard in some way will help to initiate a new market or enlarge an existing market.

2) Competitive edge: Vendors' participation in the standards development process will depend on whether they believe there are business advantages to doing so. By helping to define the standard, vendors can insure that their products will be compatible with the standard, when the standard emerges.

As with users, though, there are also costs associated with a vendor's involvement in standards development:

1) Direct costs of participation: Again, the standards development effort involves the time and energy of well-qualified experts, at considerable opportunity cost to the expert and to the vendor.

2) Sunk costs: Vendors can devote considerable resources to compatible product research, development, and production. The corporate investment in products and services that are compatible with the emerging standard may be lost if the standard is not effective at producing a market, or if it hinders market development.

3) Time to market: For vendors, delays in standards development mean that their products may never reach the market, or other technologies may leap-frog the standard.

4.2.3 Conclusions

The national ITS architecture has as its goal to provide a technical framework that will allow the development and long-term sustain-ability of a market for ITS products and services. One of the main tools to achieve such market effects is to initiate the development of consensus ITS standards. As described above, ITS standards may provide desired levels of compatibility, inter-operability, and cost savings that users need. On the other side, standards may help initiate and enlarge markets for ITS products and services, enhancing private sector participation in ITS. Open interface standards may also spur considerable technology innovation for ITS products in meeting user needs and tastes, and may also allow expansion to new technologies as they evolve.

There are several elements of the national architecture program, both to date and in the future, that will enhance the development of ITS standards. One of the chief architecture products to initiate standards efforts is a set of standards development packages, submitted separately with the *Standards Requirements* document. These packages offer an initial but comprehensive treatment of applications-level messages and interfaces for a broad range of ITS products and services. As such, they are raw material for standards development organizations (SDO's) to begin their efforts. In this regard, the national architecture may be credited with reducing the initial system engineering and systems integration groundwork that is necessary for virtually any standards development process. This has two effects: it may reduce the time to develop standards; and, it may assist in scoping of appropriate messages and interface definitions for the SDO's.

The framework of benefits and disbenefits of standards outlined above may also be useful in evaluating the benefits of particular ITS standards. Such analysis is useful in addressing priorities for ITS standards development. The determination of such priorities is addressed more directly in the *Standards Development Plan* and *Implementation Strategy* documents. Without detracting from the analysis in those documents, several conclusions can be drawn here about future efforts to facilitate standards development and adoption.

The ultimate benefits of consensus standards are in many cases large enough to keep users and vendors involved in the standards development process. At the same time, the analysis above has suggested significant risks and costs for both users and vendors associated with these efforts. Many of the risks associated with free market economics (such as failure of a market to develop) are risks that cannot be directly mitigated within the scope of the architecture or related programs. At the same time, other risks and costs from the standards development process can be addressed through follow-on activities to the national architecture program. The following paragraphs outline the key factors of standards timing, scope, and direct costs.

Timing. The point at which a standard is introduced will have significant implications for the initiation and growth of any particular ITS market. In choosing when to develop and to introduce a standard, the level of technology maturity must be balanced with the need to initiate and sustain these markets. Government efforts to support standards development should be timed in such a way as to minimize the disruption to technology research and development, but yet satisfy market demands for particular ITS products and services in a timely manner.

Scope. The standards development packages produced by the Joint Team should be evaluated within the SDO's to discern where the message sets and interfaces are too specific and where they are too general. Maintenance of the national architecture is required to maintain an appropriate level of both breadth and depth in the architecture functions and data and information flows.

Direct costs of participation. For users, the cost of participating in standards development efforts may impede their participation. This, in turn, may cause delays or even abandonment of the standard development. Government financial support, particularly for public sector end users of ITS products and services, may be warranted. This will allow faster development of truly consensus standards.

4.3 Benefits of ITS Synergy

The National ITS Architecture has considered ITS in its broadest possible terms, across the full set of 29 user services. This broad range of services means that all of the different services envisioned under ITS could be considered simultaneously in this analysis. As a result, the architecture identifies not only functions and information flows for each user service, but also those that are shared across user services. In this way, the architecture development process ensures that common functions, data and information flows are identified.

By identifying such synergy, the architecture naturally allows those who are planning, funding, designing and integrating ITS components to realize efficiencies as market packages are implemented over time. At the same time, many of the quantitative benefits of synergy are not intrinsic to the architecture itself, but are only realized as particular services are designed and implemented. The architecture alone only provides possible areas where synergy may be realized in ITS implementations. This topic is covered in more detail in the *Implementation Strategy* document. In summary, synergy that may be attributed to the national architecture, and to the market packages within that architecture, may be bundled into four different areas: common functions, necessary shared information, other shared information, and common technology. Benefits in each of these areas is discussed below.

4.3.1 Common Functions

Certain functions may be performed by multiple market packages in the architecture. In some cases, a function performed in what might be considered a “basic” market package may in turn also be performed in a more “advanced” market package. The more advanced market package therefore provides some incremental improvement on the basic package. In other cases, the market packages simply share functions, but no technical hierarchy is implied. In both cases, efficiencies are achieved when both market packages are implemented, simply because the desired functions only need to be performed once.

In this analysis, only the most salient common functions between market packages have been identified, and these are highlighted in Table 4.3-1. (explicit discussion of each of these common functions between market packages appears in Section 2.4 of the *Implementation Strategy* document). In each row of the table, a single market package on the left is logically joined with other market packages (on the right) that have common functions in the architecture.

Table 4.3-1: Synergy from Common Functions

Market Package (Source)	Market Packages with Common Functions
Network Surveillance	• Surface Street Control • Freeway Control • Emissions and Environmental Hazards Sensing
Probe Surveillance	• Emissions and Environmental Hazards Sensing • Virtual TMC and Smart Probe Data
Dynamic Toll / Parking Fee Management	• Probe Surveillance • In-Vehicle Signing • Electronic Clearance
Surface Street Control	• Regional Traffic Control • Traffic Network Performance Evaluation
Freeway Control	• HOV and Reversible Lane Management • Regional Traffic Control • Traffic Network Performance Evaluation
Traffic Network Performance Evaluation	• Regional Traffic Control • Incident Management System • ITS Planning
Traffic Information Dissemination	• Incident Management System
Broadcast Traveler Information	• Interactive Traveler Information
Interactive Traveler Information	• Dynamic Ridesharing • Yellow Pages and Reservation • ISP-Based Route Guidance
Autonomous Route Guidance	• Dynamic Route Guidance
Dynamic Route Guidance	• ISP-Based Route Guidance
ISP-Based Route Guidance	• Integrated Transportation Management / Route Guidance
In-Vehicle Signing	• Dynamic Toll / Parking Fee Management • Intersection Safety Warning
Transit Vehicle Tracking	• Transit Fixed Route Operations • Demand Responsive Transit Operations • Passenger and Fare Management • Transit Security
Transit Fixed Route Operations	• Multi-modal Coordination • Transit Maintenance
Demand Responsive Transit Operations	• Multi-modal Coordination • Transit Maintenance

Table 4.3-1: Synergy from Common Functions (Continued)

Market Package (Source)	Market Packages with Common Functions
Emergency Management	• ISP-Based Route Guidance
Mayday Support	• Transit Security • Interactive Traveler Information • HAZMAT Management
Fleet Administration	• HAZMAT Management • CVO Fleet Maintenance • Freight Administration
Freight Administration	• Fleet Administration • HAZMAT Management
Electronic Clearance	• Roadside CVO Safety • International Border Electronic Clearance
On-Board CVO Safety	• Vehicle Safety Monitoring
Vehicle Safety Monitoring	• Driver Safety Monitoring • Longitudinal Safety Warning • Lateral Safety Warning • Intersection Safety Warning
Driver Safety Monitoring	• Automated Highway System
Longitudinal Safety Warning	• Advanced Vehicle Longitudinal Control
Lateral Safety Warning	• Advanced Vehicle Lateral Control
Intersection Safety Warning	• Intersection Collision Avoidance
Advanced Vehicle Longitudinal Control	• Pre-Crash Restraint Deployment • Automated Highway System
Advanced Vehicle Lateral Control	• Pre-Crash Restraint Deployment • Automated Highway System

The benefits of this synergy to ITS system designers and planners appear in two areas:

1) Efficiencies in functional performance: In the architecture, a given function may appear in multiple market packages that in a system design only needs to be performed once. This means that potential redundancies in data collection, processing, and dissemination in an ITS system design can be avoided. These efficiency benefits take the form of cost savings in avoiding functional duplication.

2) Cost savings from common technology. When implementing market packages with common functions, only one market package containing the given function is required. In this way, the second (or third, etc.) market package that uses these common functions can leverage an existing technology (software, hardware, communications, etc.) investment. These common technology elements are identified in Section 4.3.4.

The distinction between these two kinds of benefits is subtle but important. Efficiencies in functional performance are directly attributed to the architecture-level system engineering and integration that has been performed as part of the national architecture development. Benefits of leveraging existing or proposed common technology, however, are directly attributable to deployment integration, relating to a specific ITS system design.

4.3.2 Necessary shared information

A second area of synergy comes from sharing information between market packages. In many cases in the architecture, data and information from one market package are used by another market package to provide a user service. One may then consider two levels of information sharing: *necessary*, where the provision of one market package is largely dependent on information from the other market package; and *complementary*, where the information is not critical but can result in significantly improved performance of a market package.

In this section, the necessary data flows are identified. In general, if the necessary information is not shared, a market package may not provide basic services or will provide only significantly degraded service. In this way, there is a clear dependency for data flows between market packages. Table 4.3-2 identifies these dependencies, giving the information source (market package) in the left column and the market packages needing such data in the right column. [A discussion of related information flows appears in Section 2.4 of the *Implementation Strategy* document.]

Specific benefits to ITS implementors occur through coordination of data sharing when multiple market packages are being implemented. Again, benefits may accrue in two areas:

1) Efficiencies in information management: In the architecture, specific data collection, processing and dissemination may be managed so that numerous market packages have access to the same pool of data and information. Efficiency benefits take the form of cost savings in avoiding redundant data bases and data management processes.

2) Cost savings from common technology. When implementing market packages that may share information, cost savings from the information system design and development can be achieved. Multiple users can leverage an existing investment in information technology (e.g. data base management software and hardware). Again, these common technology elements are identified in Section 4.3.4.

Again, the distinction between these two types of benefits is that the efficiency of information management is directly attributable to the architecture, while common technology is a function of a specific deployment.

Table 4.3-2: Shared Data / Information Necessary for User Services

Market Package (Source)	Market Packages Sharing Data to Perform a User Service
All Market Packages	ITS Planning
Network Surveillance	All ATIS Market Packages
Probe Surveillance	All ATIS Market Packages Surface Street Control Freeway Control
Surface Street Control	Traffic Information Dissemination
Freeway Control	Traffic Information Dissemination
Emissions and Environmental Hazards Sensing	Traffic Information Dissemination
Dynamic Toll / Parking Fee Management	Interactive Traveler Information
Regional Traffic Control	Multi-modal Coordination Integrated Transportation Management / Route Guidance Incident Management System
Incident Management System	Regional Traffic Control Emergency Response
Broadcast Traveler Information	Dynamic Route Guidance
Transit Vehicle Tracking	Broadcast Traveler Information
Demand Responsive Transit Operations	Dynamic Ridesharing Interactive Traveler Information
Transit Passenger and Fare Management	Interactive Traveler Information
Transit Security	Emergency Response
Mayday Support	Emergency Response
Emergency Response	Emergency Routing Transit Security Incident Management System
Roadside CVO Safety	On-Board CVO Safety
HAZMAT Management	Emergency Response
Commercial Vehicle Administrative Processes	Electronic Clearance
Fleet Administration	Commercial Vehicle Administrative Processes

4.3.3 Other shared information

In other cases in the architecture, information may be shared between market packages that enhances, but may not entirely be critical, to the performance of specific services. Through the many data flows and interfaces, the architecture identifies how organizations can share data and information. From the perspective of benefits, these data and information flows can be used for better transportation system management and operations. Hence, the sharing of transportation system performance data through the architecture may lead to more effective use of scarce transportation resources and better system-wide planning (e.g. with traffic and transit management, multi-modal coordination).

Because the architecture is a fully connected system, information sharing is possible between all major center subsystems for the purpose of enhancing transportation management and operations. Given this level of connectivity that is inherent to the architecture, the types of benefits that may be realized are will occur in system design and deployment. Benefits and potential obstacles to system integration, at the level of local deployment decisions, are addressed more fully in Section 4.3 of the *Implementation Strategy* document. In general, that section identifies the possible benefits of transportation system coordination that might be achieved through cooperative information sharing. The four areas of benefits are cited below for completeness of this section; the reader is referred to Section 4.3 of the *Implementation Strategy* document for additional details.

- <u>Improved data collection and utilization</u>: an integrated transportation management system may reduce costs of obtaining, processing, and disseminating data, because of reduced duplication of effort and increased sharing of information.

- <u>Improved system performance</u>: Traffic congestion, energy consumption, and air pollution may be reduced as a result of synchronized operations, such as smoother traffic flow, faster incident response, and coordinated traffic diversion plans.

- <u>Increased reliability of the overall transportation system</u>: An integrated system facilitates the development of a set of coordinated plans and procedures to handle different incident situations.

- <u>Enhanced opportunities for cooperation</u>: Productive, cooperative partnerships between public sector agencies, and between the public and private sectors, may be promoted by having a common platform to discuss and resolve issues.

4.3.4 Common technology in system design

Finally, data flows and functions specified in the architecture may be combined, in a specific system design, to leverage common technology. It is important to keep in mind that the architecture itself does not specify the specific technologies that may be used. The national architecture does identify common functions and shared information, but it does not specify possible system designs that may aggregate different architecture flows into a common media.

Nonetheless, the comprehensive nature of the national architecture does suggest that there is synergy that may be realized in using common components and communications technologies for many of the ITS market packages. Several salient examples of technologies that are good candidates for common applications are identified in Table 4.3-3. The technologies identified in this table are relatively mature, with commercial applications that currently provide the level of functionality required by most ITS market packages. In addition, these technologies also have applications across a broad range of market packages.

Table 4.3-3: Mature Technologies with Multiple Market Package Applications

Technology Area	Technologies
Transportation Technologies	• Traffic sensors

	• Vehicle condition monitoring
Communications	• Broadcast communications • Two-way interactive communications • Dedicated short-range communications • Wireline communications
Information Management	• Data base and information management systems • Map data bases
Other	• Electronic payment media • Location determination

A more comprehensive treatment of possible technology synergy from the national ITS architecture would look at technology requirements for each market package and identify other possible market packages that use similar technologies. To this end, Table 4.3-4 identifies functional groups of technologies and relates them to the market packages. Each column in the table represents a general technology area that may be applied through one (or more) of the market packages.

The technology requirements for each market package are presented in the table using the following icons:

■: The opaque (black) squares denote a critical (i.e. required) relationship between the market package and the technology area.

❑: The transparent (white) squares denote a relationship in which the technology enhances the services or features of the market package but is not strictly required.

Table 4.3-4: Common Technology Areas by Market Package

	Market Packages	Technology Area																							
		Sensor										Comm								User I/F			Control		
		Traffic	Vehicle Status	Environment	Vehicle Monitoring	Driver Monitoring	Cargo Monitoring	Obstacle Ranging	Lane Tracking	Security	Location Determination	Cell-Based (U1t)	Vehicle-Roadside (U2)	Vehicle-Vehicle (U3)	Broadcast (U1b)	Fixed (W)	Algorithms	Information Mgmt	Payment	Driver	Traveler	Operator	Signals	Signs	Vehicle
ATMS	Network Surveillance	■		❑												■	❑	■				■			
	Probe Surveillance				■						■	■	❑			❑	■	■				■			
	Surface Street Control	■														■						■	■		
	Freeway Control	■														■						■	■	❑	
	HOV and Reversible Lane Mgmt	■	■								■	■				■	❑					■	■	■	
	Traffic Information Dissemination														■	■	❑	■				■		❑	
	Regional Traffic Control	■			■											■	■	■				■	■	■	
	Incident Management System	■			■						■	■				■	■	■				■	❑	❑	
	Traffic Network Performance Eval	■			■											❑	■	■				■			
	Dynamic Toll/Parking Fee Mgmt	■	■									❑	■		❑	■	■	■	■	■		■	❑	❑	
	Emissions and Environmental Haz.		■	■	❑											■	■	■		❑		■		❑	
	Virtual TMC and Smart Probes				■						■	■	❑			❑	■	■				■			
APTS	Transit Vehicle Tracking				❑	❑					■	■	❑			❑		■			❑	■			
	Transit Fixed-Route Operations											❑	❑			❑		■		❑	❑	■			
	Demand Response Operations											■				❑	❑	■		■	❑	■			
	Transit Passenger and Fare Mgmt									❑	❑	❑				❑		■	■		■	■			
	Transit Security									■	❑	❑				❑		❑		■	■	■			
	Transit Maintenance				■	❑					❑	❑				❑		■		■		■			
	Multi-modal Coordination										■	■	■			■	❑	■		■		■			
ATIS	Broadcast Traveler Information	■		❑											■	■	■	❑		■	■	■			
	Interactive Traveler Information	■		❑							❑	■				■	■	❑		■	■	■			
	Autonomous Route Guidance										■						■	❑		■	■				
	Dynamic Route Guidance	■		❑							■	❑			■	■	■	❑		■	■				
	ISP-Based Route Guidance	■		❑							■	■				■	■	■	❑	■	■	■			
	Integrated Transportation Mgmt/RG	■		❑							■	■				■	■	■	❑	■	■	■			
	Yellow Pages & Reservation										❑	■				■	■	❑		■	■	■			
	Dynamic Ridesharing									❑		■				■				■	■	■			
	In Vehicle Signing		❑	❑	❑	❑	❑				■	❑	■			❑	❑	❑		■		❑			
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 Ctrl				■	❑		■									■			■					■
	Advanced Vehicle Lateral Control				■	❑		■	■								■			■					■
	Intersection Collision Avoidance		■	❑	■	■		■	■			❑	■	❑		■	■	❑		■			❑	❑	■
	Automated Highway System	❑	■	❑	■	■		■	■	❑	■	■	■	■		■	■	■	❑	■		■	❑	❑	■
CVO	Fleet Administration				■						■	■	❑			❑	❑	■		■		■			
	Freight Administration						■				■	■	❑			■	❑	■		■		■			
	Electronic Clearance												■			■		■		■		■	❑	❑	
	CV Administrative Processes											❑				■		■							
	International Border Clearance												■			■		■		■		■	❑	❑	
	Weigh-In-Motion		■										❑				❑					■	❑	❑	
	Roadside CVO Safety		■		❑		❑						■			■	❑					■	❑	❑	
	On-board CVO Safety				■	■	■					❑	❑				❑			■					
	CVO Fleet Maintenance				■						■	■				❑	❑	■		■		■			
	Hazmat Management						■				■	■	❑			■	❑	■		■		■			
EM	Emergency Response									■	❑	❑				■	❑	■				■			
	Emergency Routing				❑	❑					■	■	❑			❑	❑	■		■		■			
	Mayday Support		❑								■	■				■		❑		■	■	■			
	ITS Planning													■		■		■				■			

Through this table, the benefits of common technology for different market packages can be identified. For example, if a local public agency were interested in installing a regional traffic control system, synergy in technology development and/or use could occur in several areas:

- Traffic sensors may already exist from local signal control devices or other existing surveillance hardware.
- A video-based vehicle monitoring system may have already been set up to assist with incident detection and management.
- A public or private wireline infrastructure associated with an emergency response system may be available for purchase or lease.
- Local traffic managers may already have software for surveillance data processing, storage and dissemination. The regional traffic control system can leverage this existing software in making additional purchases.

In this way, possible ITS-related technology synergy can be identified and exploited in ITS system designs.

Chapter 5
Benefits of ITS

This chapter describes the results of the analysis of ITS benefits conducted by the Joint Team. This chapter traces the benefits assessment from the development of benefits metrics (in Section 5.1) to the qualitative assessment of the benefits of particular ITS market packages. These benefits are presented by market package (or market package bundle) in Section 5.2. The choice to present these by market package was to make the benefits analysis feed the architecture's evolutionary deployment strategy and implementation plan. Since the market packages are likely to be the increment by which the architecture is deployed, it was believed that such a format would be more suitable to the results.

In addition, Section 5.2.8 presents a benefits accrual matrix that shows how the benefits of various ITS services are distributed between individual users, public and private organizations, and society as a whole. To conclude the benefits assessment, Section 5.3 traces the benefits for each of the market packages, and for the architecture as a whole, and ties them into the national goals for ITS. In this way, the link between market packages, benefit metrics, and finally national goals is described.

5.1 ITS Benefits Metrics

The benefits of ITS for the transportation system are dependent on many different aspects of the national architecture and its impact on system designs. Support for different products and services, the information processing capabilities, the level of accuracy of information, and the location of information processing are just a few of the aspects of the architecture that will directly affect the level of benefits achievable by that system. A number of different benefits metrics may be addressed in this analysis. These are grouped roughly in accordance with the six ITS goals identified in Section 3.1 as:

1. Improve Operational Efficiency and Capacity
2. Enhance Mobility, Convenience and Comfort
3. Improve Safety
4. Reduce Energy Consumption and Environmental Costs
5. Increase the Economic Productivity of Individuals, Organizations, and the Economy as a Whole
6. Create an Environment in which the Development and Deployment of ITS can Flourish

Table 5.1-1 gives a set of benefits metrics that can be used to qualify and quantify each of these ITS goals. These echo similar types of metrics suggested by the *Mission Definition* document, the ITS National Program Plan and other documents. The paragraphs that follow describe the assessment of these metrics for the six goals identified above. These metrics, in turn, are used to characterize the benefits of ITS market packages in section 5.2.

Table 5.1-1. Benefits Metrics

ITS Goal	Related Metric
Increase Transportation System Efficiency and Capacity	Traffic Flows / Volumes / Number of Vehicles
	Lane Carrying Capacity
	Volume to Capacity Ratio
	Vehicle Hours of Delay
	Queue Lengths
	Number of Stops
	Incident-related Capacity Restrictions
	Average Vehicle Occupancy
	Use of Transit and HOV modes
	Intermodal Transfer Time
	Infrastructure Operating Costs
	Vehicle Operating Costs
Enhance Mobility	Number of Trips Taken
	Individual Travel Time
	Individual Travel Time Variability
	Congestion and Incident-related Delay
	Travel Cost
	Vehicle Miles Traveled (VMT)
	Number of trip end opportunities
	Number of Accidents
	Number of Security Incidents
	Exposure to Accidents and Incidents
Improve Safety	Number of Incidents
	Number of Accidents
	Number of Injuries
	Number of Fatalities
	Time Between Incident and Notification
	Time Between Notification and Response
	Time Between Response and Arrival at Scene
	Time Between Arrival and Clearance
	Medical Costs
	Property Damage
	Insurance Costs
Reduce Energy Consumption and Environmental Costs	NO_X Emissions
	SO_X Emissions
	CO Emissions
	VOC Emissions
	Liters of Fuel Consumed
	Vehicle Fuel Efficiency
Increase Economic Productivity	Travel Time Savings
	Operating Cost Savings
	Administrative and Regulatory Cost Savings
	Manpower Savings
	Vehicle Maintenance and Depreciation
	Information-Gathering Costs
	Integration of Transportation Systems
Create an Environment for an ITS Market	ITS Sector Jobs
	ITS Sector Output
	ITS Sector Exports

5.1.1 Increase Transportation System Efficiency and Capacity

Transportation system performance, to a large degree, may be represented by aggregate measures of system capacity and the productive use of that available capacity. The measures listed in Table 5.1-1 corresponding to transportation system efficiency and capacity can generally be grouped as follows:

1) Measures of transportation infrastructure capacity and use: traffic flows, lane capacity, volume-to-capacity (V/C) ratios, incident-related capacity restrictions, intermodal transfer time.

2) Measures of congestion: vehicle hours of delay, queue lengths, number of stops.

3) Measures of vehicle capacity and use: average vehicle occupancy, use of transit and HOV modes.

4) Measures of operating cost efficiency: infrastructure operating costs, vehicle operating costs.

All of these measures suggest that they may be quantitatively estimated. However, some of these measures are more easily quantified than others. Well-established measures that are commonly used by traffic engineers include traffic flows, lane capacities, V/C ratios, and infrastructure operating costs. Other measures, such as incident-related capacity restrictions, vehicle hours of delay, queue lengths, the number of stops, and vehicle occupancy are typically much more difficult to measure, simply because the costs and technology to capture such data are prohibitively expensive.

More directly, given the quantitative nature of these data, one may be interested in measuring the impacts of different ITS market packages on transportation system performance. One most obvious source are empirical data from specific demonstrations, operational tests, or on-going field trials. Nonetheless, the costs of collecting specific measures of effectiveness (MOEs) can be prohibitive, even in these tests. The alternative, at this point, rests in transportation system modeling and simulation. The limitations of these models, however, cannot be overstated. Each of the existing traffic modeling tools are developed and implemented with a large set of assumptions. These applications are, at best, only preliminary guesses at the response to ITS products and services, and at worst can be very misleading on the scale and scope of ITS benefits. To date, the transportation system simulation and modeling tools are largely inadequate to model the traffic, transit, air quality, and safety benefits of ITS services.

5.1.2 Enhance Mobility

Mobility may be measured in both quantitative and qualitative terms. In general, however, what we mean by mobility can be described in terms of improving the current conditions under which people travel, providing new opportunities for travel and greater access to travel options. One may characterize mobility based on each individual’s travel behavior, taking into account the characteristics of the activities a person may engage in at both ends of the trip, as well as the characteristics of the trip itself. In this way, an improvement in mobility is described as an improvement in a traveler’s access to certain trip-end activities, by improving travel (or even non-travel) options. As such, it is difficult to select a set of measures to capture this objective. Most generally, the measures of travel demand cited above (e.g., changes in origin-to-destination travel volumes, mode shift, route choice, etc.) do attempt to capture these changes in individual mobility. However, it is important to keep in mind that these measures only act as a proxy for the goal of increased “mobility.”

This suggests that measuring, or even describing, how ITS may affect mobility is a daunting task. Nonetheless, specific measures, such as those listed in Table 5.1-1, may be used to capture (at least in proxy form) the kinds of mobility benefits that are suggested for ITS. The table includes both aggregate measures, such as VMT, the number of trips taken, and the number of accidents and incidents, to more individual (or disaggregate) measures, such as the travel time and cost for a particular individual making a particular trip. These types of measures more easily capture quantitative benefits to the individual traveler.

It is important to bear in mind that specific measures of mobility reflect only the most obvious (and easily observed) aspects of individual travel behavior. Mobility, on the other hand, encompasses the broad range of traveler behavior and decision-making: whether or not to travel, how many trips to take, where to go, on what modes to travel, at what time to travel, on what routes to travel, where to get information about travel options, etc. As a result of these choices on the part of individual travelers, they may experience improved travel performance; that is, they perceive benefits from making these travel choices. Thus, benefits appears as a net of two items: an improvement in the benefits of engaging in activities that require travel, minus the “generalized cost” of travel, including not only the time and monetary cost of travel, but also factors such as convenience, comfort, safety, etc. The travel demand decisions that improve these net benefits result in improved mobility.

5.1.3 Improve Safety

The net safety improvements as a result of ITS services and products are dependent on a number of factors. Safety itself is a complex issue, and may be considered relevant to the assessment of ITS in three ways:

1. A market package (or user service) may be intended to reduce safety-related accidents, resulting in reduced casualties and property damage.
2. A service may (positively or negatively) affect safety in normal operation. For example, maps or direction indicators may help a driver unfamiliar with an area to proceed more directly (and thus more safely) to his/her destination. Alternatively, the same devices may distract a driver’s attention from the road, thereby reducing the overall level of safety.
3. As a result of poor specification, poor design or faults in components a service may cause casualties or property damage that would not otherwise have occurred.

The first element is addressed below, and the second two elements are discussed later in this section.

ITS Market Package Safety Benefits

The specific safety benefits of any particular market package can be identified inasmuch as that package helps to make the broader transportation system more safe. Specific measures of benefit include number of accidents and their severity, injuries, fatalities, and property damage. It is believed that credible estimates of such safety benefits of ITS requires detailed information about accidents and the specific factors that cause them. Moreover, any number of factors can contribute to traffic accidents. Thus, isolating particular factors and determining the potential improvement in safety from ITS products and services requires a very detailed knowledge of accidents and their causes.

The data on accidents, their severity, and the many factors that cause them are generally not available to the public. In lieu of this, aggregate analysis could be proposed; however, such analysis is clearly limited in that only the most general conclusions can be developed. Such analyses are again subject to any number of assumptions about accidents, their causes, and the success of ITS products to prevent these accidents. As a result, these more aggregate analyses are not reliable. Instead, a more comprehensive and accurate measurement of safety benefits requires detailed accident data. NHTSA collects an annual sample of accident data (on an accident-by-accident basis), but the use of that data is restricted. However, recently NHTSA has employed several contractors who, using national data, have used these data to estimate the potential benefits of those user services (or market packages) which are intended to affect safety. These studies provide considerable evidence of the benefits of ITS services for both reducing the severity of and preventing accidents.

System Design-Related Safety Benefits

At the same time, supplementing these direct transportation-related safety benefits is the need to examine the safety of the ITS architecture and related system designs. Indeed, system safety is clearly sensitive to the design of particular ITS services. That is, the circumstances under which the system design requires use of degraded modes, and so the probability that degraded modes occur, will have a large effect on the number of system-related casualties and/or property damage. Other effects, on the other hand, will be sensitive to the way a market package is deployed, but will not be greatly affected by the design of the system itself.

For any ITS system design, a high-level hazard analysis is necessary, identifying, but perhaps not quantifying, possible failures in a particular ITS system and their resulting effects on system operation. In the context of information management, we should note that the effects on safety of a failure to receive a message, receipt of a meaningless message, and receipt of a message bearing a wrong meaning may be very different. These effects will depend on the design of each market package, as it is deployed. Certainly a well-designed package will not permit a single communication failure to generate a highly-critical hazard. We can thus identify the different effects of these complications and costs they impose on the system design and the level of criticality of the hazards they may generate.

5.1.4 Reduce Energy Consumption and Environmental Costs

The level of fuel consumption and possible environmental costs of the transportation system may be measured on several different levels. Most directly, measures such as liters of fuel consumed, vehicle emissions measures, and vehicle fuel efficiency provide quantitative measures of the attainment of this goal (from Table 5.1-1). These measures, in turn, are highly dependent on the types of trips that travelers make and all the multitude decisions made in choosing to travel. More typically, specific measures of vehicle emissions and fuel consumption are based on other travel metrics, perhaps even on a per-trip basis, such as:

- Travel time
- Queuing time
- Number of stops
- Number of accelerations
- Kilometers / miles traveled
- Speeds

Fuel consumption and emissions levels are also highly dependent on the type of vehicle, its age, its engine and exhaust system, its fuel delivery system, etc. As a result, direct quantitative estimates of fuel consumption and emissions are difficult without considerable assumptions about these types of parameters. As a result, the state of practice in identifying fuel consumption and emissions impacts of ITS services is primitive at best, and deserves considerably more research attention.

5.1.5 Increase Economic Productivity

Both personal and business decisions to invest in ITS will depend on the extent to which specific, quantifiable economic benefits can be shown from these technologies. From an economic perspective, specific measures of benefit could include (from Table 5.1-1):

- Travel time savings
- Operating cost savings
- Administrative and regulatory cost savings
- Manpower savings
- Vehicle maintenance and depreciation

In as much as these measures may be quantified, stronger arguments for personal and business investments can be made, and long-term economic benefits may be realized. The particular calculation of such benefits, however, depends critically on the uses of information and the extent to which ITS and information are used to change operating strategies and long-term resource allocation decisions.

5.1.6 Create an Environment for an ITS Market

One final element in this assessment is the ability of the architecture to create a market for ITS products and services. While this was discussed in Chapter 4, specific measures of performance of the ITS sector that are quantifiable include:

1) ITS-related jobs.

2) ITS-related output.

3) ITS-related exports.

Due to the myriad uncertainties regarding the development of public, private, and public-private cooperative efforts in ITS, it is very difficult to estimate, let alone forecast, such estimates. Typically, estimates of these metrics examine particular aspects of the market: the involvement of the public sector in investment, policy, and regulation; the amount of research, development, testing, and product commercialization in the private sector, and various other aspects of the architecture and system designs. These topics, and their influence on the market for ITS products and services, are discussed in greater detail in the *Implementation Strategy* document.

5.1.7 Benefits Flow Diagrams

This section addresses the need to connect the benefits metrics identified above with the proposed 53 market packages that are elements of the national architecture. The purpose of such an analysis is to demonstrate a logical connection of the Joint Team's market packages to the specific metrics described in Table 5.1-1. This allows a preliminary causal inference of quantitative benefits for particular market packages. Once these connections are made, the performance metrics may in turn be logically connected to the six ITS goals mentioned above.

The tool used to describe this process is what we call the "benefit (or logic) flow diagram." In this diagram, arrows are used to show logical dependencies between market packages from the architecture and specific performance metrics, and between these metrics and the ITS goals defined above. A simple schematic for these diagrams is shown in Figure 5.1-1. These diagrams are helpful to the process of benefits identification and quantification in the following ways:

1) *The diagrams show what transportation performance metrics are affected by each market package.* A given market package may influence a number of aspects of the transportation system.

2) *The diagrams show the range of market packages that may influence each of the transportation performance metrics.* A particular set of market packages will work in concert to produce certain improvements in the transportation system. By working through these diagrams, the particular user services that influence a performance metric may be identified. In this way, desired performance metrics may be enhanced by changes in the implementation of specific market packages.

3) *The diagrams show the complexity of relationships among different performance metrics.* The logical dependencies among different performance metrics can be shown. The complex interactions of these metrics in describing the transportation system may be outlined.

4) *The diagrams demonstrate the logical connection of transportation performance metrics to the broader goals of ITS.* The daily operation of the transportation system itself has broader repercussions for the transportation system as a whole, for air quality, fuel consumption, safety, and economic productivity. These connections can be shown in this set of diagrams.

One important fact to be kept in mind for these logic flow diagrams is that the diagrams present only **logical dependencies** among different elements. In no way can we infer the magnitude of these connections, or in some cases even the direction of the dependency, based on the diagrams alone. The point is to show the logical connection only, and not the strength or magnitude of that connection.

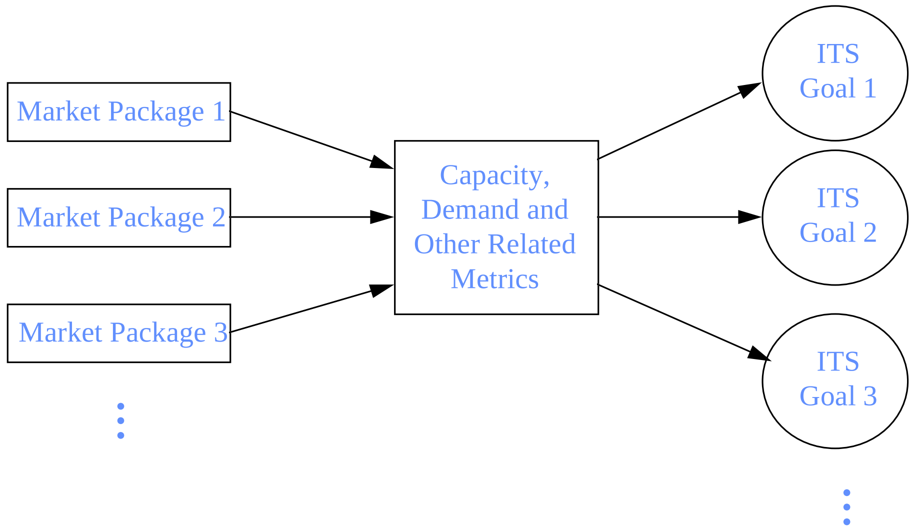

Figure 5.1-1. Benefits Flow Diagram Schematic

The analysis approach defines these flow diagrams in terms of the immediate connection of each of the 53 market packages to the transportation system metrics in Table 5.1-1. A second set of logic flow diagrams, connecting these benefits metrics to the six ITS goals, is also generated.

To cover all 53 market packages with sufficient logical arguments is a lengthy set of text and diagrams. To facilitate document readability, these flow diagrams and connections appear in Appendix A. However, these connections are critical to the estimate of qualitative benefits (in Section 5.2) and the connection of market packages to ITS goals, in Section 5.3.

5.2 Qualitative Estimates of ITS Benefits

Through the deployment of the National System Architecture, there are likely to be benefits accruing to a wide variety of users, non-users, and society as a whole. It is important to keep in mind here that the results presented here represent the benefits of the implementation of ITS, not benefits of the architecture *per se*. In the sections that follow, a preliminary quantitative and qualitative analysis of these benefits is presented. For the ease of presentation, the benefits are grouped according to particular market package bundles, namely:

1. Traveler Information
2. Traffic Management
3. Transit Management
4. Commercial Vehicle Operations
5. Vehicle Safety Systems
6. Emergency Management
7. ITS Planning

5.2.1 Traveler Information Market Packages

One of the often-cited benefits of ITS for individual users is improved trip planning and real-time information on transportation options. Market packages in the National Architecture that address these types of services include:

- Broadcast Traveler Information
- Interactive Traveler Information
- Autonomous Route Guidance
- Dynamic Route Guidance
- ISP Based Route Guidance
- Integrated Transportation Management/Route Guidance
- Yellow Pages and Reservation
- Dynamic Ridesharing
- In Vehicle Signing

Benefits of these packages are shown in Table 5.2-1. Traveler information may take a number of forms. With pre-trip information, travelers may be able to modify their travel behavior in response to real-time transportation system conditions. This may involve changes in departure times, route choice, mode choice, or even whether to make a trip or not. The benefits realized by the individual often depend on just how much flexibility he/she has in making these decisions. For this reason, it is often difficult to characterize the potential benefits of changes in departure times or mode choices. Obviously, the level of flexibility in making departure time or mode choices will heavily influence the level of benefits of pre-trip information. However, one may expect that the benefits of such systems are at least as great as those systems that provide real-time information on route choices (given that one may modify route choices before as well as during the trip).

Table 5.2-1: Likely Benefits of Traveler Information Market Packages

Market Package	Likely Benefits	Context Where Benefits May Accrue
Broadcast Based ATIS	• Possible benefits as high as other interactive ATIS services (see below), depending on capability of in-vehicle devices	• Primary value for incident-related (accidents, weather, special events, etc.) traffic delays, across all geographic areas • Higher benefits to travelers with long trips, multiple mode and route alternatives
Interactive Traveler	• Reduction in travel time for equipped	• Primary value for incident-related (accidents,

Information	travelers • Increases in speeds, decrease in number of stops for equipped travelers • Some benefits for non-equipped travelers • Higher benefits for pre-trip versus on route information • Decreasing benefits with higher market penetrations	weather, special events, etc.) traffic delays, across all geographic areas • Higher benefits to travelers with long trips, multiple mode and route alternatives • Decreasing benefits with higher network loadings (i.e. higher congestion)
Autonomous Route Guidance Dynamic Route Guidance ISP Based Route Guidance Integrated Transportation Management/Route Guidance	• Reduction in travel time for equipped travelers • Increases in speeds, decrease in number of stops for equipped travelers • Some benefits for non-equipped travelers • Higher benefits for pre-trip versus en route information • Decreasing benefits with higher market penetrations	• Primary value for incident-related (accidents, weather, special events, etc.) traffic delays, across all geographic areas • Higher benefits to travelers with long trips, multiple mode and route alternatives • Higher benefits for visitors and other unfamiliar travelers
Yellow Pages and Reservation	• Potential reduction of VMT spent searching for trip destinations	• Benefits highest for visitors and other unfamiliar travelers • Familiar travelers benefit from parking reservation
Dynamic Ridesharing	• Increased vehicle occupancy and use of HOV modes • Improved individual mobility	• Significant density of related trips is necessary to ensure ride matching
In Vehicle Signing	• Reduction in search time and excess VMT • Reduction in accidents	• Anticipated benefits in congested areas, night driving, rural areas • Aid to visually challenged drivers

Continuing in this line of thought, moreover, it is widely believed that in situations where travelers have a considerable number of route options, route planning advice based on real-time information may offer some benefit to the driver, through reduced travel times, increased travel time predictability (by avoiding non-recurring congestion), and less delay (e.g., queuing) time.

One additional level of functionality provided by these market packages is on-board information about getting to the destination. In particular, information on location, traffic conditions, traffic signs, and parking availability could be given to the individual to reduce uncertainty in reaching his/her destination. This "static" routing capability may have some benefit; it is estimated that 2-3% of all VMT is wasted as additional mileage spent searching.

Besides providing individual benefits, trip planning and other ATIS services may also improve the overall performance of the transportation system more generally. While in most cases the primary motivation for implementing these market packages is to improve individual travel and mobility, there may also be significant benefit to the transportation system at large. Again, the benefits to the transportation system can be seen as the sum of a number of individual decisions taken in response to better information about the system performance. Based on information, travelers may choose to alter their departure time, route, or mode, or may choose to forego a trip altogether. Taken in the aggregate, the net impact on the transportation system may be substantial.

5.2.2 Traffic Management Market Packages

Traffic management functions are expected to improve traffic flow in the transportation network through traffic signals and other controls, incident detection and management, and demand management. At the highest level, the benefits of improved traffic flow through traffic management and control measures accrue to the traveling public at large, but may also be identified as being of benefit to individual travelers inasmuch as these systems improve individual trip-making. In the National Architecture, these functions are found in the following market packages:

- Network Surveillance
- Probe Surveillance
- Surface Street Control
- Freeway Control

- HOV and Reversible Lane Management
- Traffic Information Dissemination
- Regional Traffic Control
- Incident Management System
- Traffic Network Performance Evaluation
- Dynamic Toll/Parking Fee Management
- Emissions and Environmental Hazards Sensing
- Virtual TMC and Smart Probe Data

Benefits of such market packages are shown in Table 5.2-2. There is to date a wide variety of experience with these types of traffic management services, providing much more empirical evidence about their value and applicability in a number of different localities. In the documented cases, however, one must be careful to examine the system-wide effects of the traffic management system, not just the local impacts. While these benefits may often appear small when documented for the individual traveler, they add up to large amounts of time savings in the context of a large traffic network with hundreds of thousands of drivers each day.

Traffic signal coordination systems seem to have some contribution to reducing total network travel times under recurrent congestion. Alternatively, there may also be considerable benefit to management of non-recurring congestion, typically associated with roadway incidents. It is widely believed that such non-recurring congestion is responsible for over 50% of the congestion in the U.S. today. Thus, if the number or duration of incidents may be reduced, the level of traffic congestion may be reduced considerably. For the individual driver, these benefits are realized through less delay time on the road network.

Table 5.2-2: Likely Benefits of Traffic Management Market Packages

Market Package	Likely Benefits	Context Where Benefits May Accrue
Network Surveillance	• Indirect benefits only • Data support for other ATMS services	• Essential component for incident detection and sometimes for signal control • Higher value for regions where traffic patterns are transient and unpredictable
Probe Surveillance	• Indirect benefits only • Data support for other ATMS services	• Essential component for incident detection and sometimes for signal control • Higher value for regions where traffic patterns are transient and unpredictable
Surface Street Control	• Reduction in travel time • Reduction in queue time • Increase in speeds • Reduction in stops • Reduction in fuel consumption • Reductions in VMT • Reductions in HC and CO emissions • Reduction in intersection-related accident rates, with higher reductions possible for left-turn accidents • Significant benefit-to-cost ratio	• Most surface street systems will benefit from this market package • Cities with major traffic generators such as theme park or stadium will benefit more • It is expected that signal coordination tailored to specific local traffic patterns can have significantly higher benefits
Freeway Control	• Increase in freeway speed (before-after) during congested peak hours, depending on level of congestion • Increase in freeway throughput • Reduction in travel time • Reduction in queue time • Reduction in fuel consumption • Reduction in emissions	
Regional Traffic Control	• Uncertain level of benefits, but can be significant in many instances	• High benefits in regions with many cities or jurisdictions
HOV and Reversible Lane Management	• Largely unknown level of benefits	• Regions that respond by substantial shifts from SOVs to HOVs
Incident Management System	• Reduction in incident response times for large urban areas • FSP programs report significant reductions in incident-related vehicle hours of delay • Significant benefit to cost ratio	• Regions with high frequency of incidents • Regions where incident delays constitute a substantial part of delays
Traffic Information Dissemination	• Positive value but quantitative estimates have yet to be determined	• Regions where travelers respond to traffic information by either changing departure time, route choice, etc. • Regions that have alternate routes, mode choices, etc.
Traffic Network Performance Evaluation	• Reductions in data collection cost • Benefits depend heavily on current surveillance and analysis activities	• Regions that have TDM programs • Regions that have traffic management plans responding to performance evaluation
Dynamic Toll / Parking Fee Management	• Reduce peak hour congestion • Reduction in toll plaza operating costs • Reduced incidents and emissions	
Emissions and Environmental Hazards Sensing	• Reduce incident rate • Improve air quality	• High value in geographic areas in air quality non-attainment
Virtual TMC and Smart Probe		• Assumed value in rural and inter-urban areas with low capital

These traffic management benefits have obvious implications for the transportation system as a whole. Reductions in vehicle hours of delay, network stops (and corresponding accelerations), and increases in network speeds will result in more significant reductions in vehicle emissions and fuel consumption. However, reliable and reasonable models to estimate air quality and fuel consumption impacts are currently in development and are as such not directly useful for this analysis. In addition, the advantages of more sophisticated traffic signal coordination systems is still largely unknown.

The ITS community also appears sensitive to the fact that improvements in transportation system performance may also result in induced travel. That is, because many of the market packages have the effect of improving traffic flow and reducing travel times, additional demand for vehicle travel may result. While the factors causing induced demand are well understood, the resulting demand impacts are very difficult or nearly impossible to quantify. Yet, the concern of adding more vehicles to an increasingly congested traffic network may seem daunting, and critics of ITS have used this argument to believe the ITS program is misguided.

However, the impacts of increasing transportation system capacity and the subsequent increase in induced travel may be countered with various public and even private-sector policies. At a systems level, there may be benefits that accrue from market packages to enhance public transit and other high-occupancy vehicle modes. To date, however, there has been only limited investigation of either regulatory or economic measures to reduce or at least stem the growth of automobile travel. However, there has been only very limited research connecting the potential demand management strategies that may be implemented in hand directly with ITS and other information technologies.

One demand management measure that has perhaps received the most attention to date is congestion pricing, in which new or increased tolls are charged for travel during peak periods. This may be made possible by ITS-related features such as vehicle AVI tags or drivers' smart cards, through which electronic (and thus automated) toll collection may be enabled. It is believed that the resulting pricing policies will have the effect of reducing vehicle travel during peak periods, thus reducing congestion and improving air quality and reducing fuel consumption. In the United States, there has been only very limited political action to introduce such economic measures in reducing travel.

5.2.3 Transit Management Market Packages

Seven market packages are included in the realm of transit management (excepting those associated with traveler information), including:

- Transit Vehicle Tracking
- Transit Fixed-Route Operations
- Demand Response Transit Operations
- Transit Passenger and Fare Management
- Transit Security
- Transit Maintenance
- Multi-modal Coordination

Qualitative benefits of these market packages are listed in Table 5.2-3. To date, there is little well-documented evidence of the benefits to individual travelers of particular ITS-related improvements in transit management. From the perspective of the individual traveler, there are several enhancements to public transportation operations that will affect demand for these services and improve mobility provided by such services. The passenger and fare management service may make transit travel more convenient, through allowing passengers to pay their fares electronically rather than having to worry about carrying cash and loose change. Also, the transit security market package may allow a higher level of security for transit passengers, thus alleviating the fear of crime that may prevent some travelers from using public transportation.

Table 5.2-3: Likely Benefits of Transit Management Market Packages

Market Package	Likely Benefits	Context Where Benefits May Accrue
Transit Vehicle Tracking	• Improvement in vehicle on-time performance • Reductions in field supervision	• Higher benefits to areas with significant transit service reliability problems
Fixed-Route Operations	• Improved productivity of vehicles, labor	• All transit scenarios
Demand-Responsive Operations	• Improved productivity of vehicles, labor • Efficiencies in routing and trip scheduling	• All transit scenarios
Passenger and Fare Management	• Passenger convenience of common fare instrument • Reduction in cash handling losses	• Benefits clearest where multiple agencies share services, transfers, etc.

	• Reduction in costs of data collection and fare processing	
Transit Security	• Faster response to incidents • Record of security incidents	• High benefits in less secure areas (e.g. large urban areas)
Transit Maintenance	• Effective scheduling of maintenance activities • Reduction in maintenance and system repair costs	• All transit scenarios
Multi-modal Coordination	• Reduction in transit travel times from signal priority	• Good institutional cooperation between traffic and transit managers is necessary • Level of benefits depends on ambient traffic volumes and cross traffic in selected corridors or in area-wide systems

The transit vehicle tracking and transit operations market packages allow real-time and longer-term adjustments to transit service to increase the effectiveness of the service, in the form of reducing passenger travel times and passenger travel time variability (service reliability). These market packages also support more radical transit services that may provide a much higher level of mobility: a personalized public transit service (one of the FHWA's 29 user services). These types of services would yield levels of mobility to public transit passengers that are currently only available through the private automobile or taxi. In this way, these APTS market packages may serve to attract significant numbers of travelers to transit, and may enhance their trip-making through these direct service improvements.

In addition to these passenger-related benefits, cost and productivity improvements may also be realized within the transit industry. Market packages that may improve these management aspects of transit service include: passenger and fare management, transit vehicle tracking, fixed-route and demand-responsive operations, and transit maintenance. The passenger and fare management and transit vehicle tracking market packages provide real-time information to improve transit service. By collecting passenger load and vehicle location information automatically, this reduces the need for manual data collection and increases the accuracy of this data. Moreover, the availability of this data allows for improved service planning, thereby enhancing the job of making transit service more cost-effective and efficient. Costs associated with service planning and maintenance planning may be reduced by automating the routing and scheduling of services. In addition, electronic vehicle tracking and vehicle condition monitoring (in the transit vehicle maintenance market package) allow for reduced manual collection of such information in the field, thereby reducing labor costs.

While these packages for public transit agencies are intended to reduce costs and increase productivity, there is only limited experience with these types of services to date. Few agencies have available resources to evaluate the impacts of these new technologies. In cases where an evaluation has been performed, potential financial gains from automating vehicle monitoring and service planning tasks are often lost to increased hardware and software costs, training of personnel, and operations and maintenance of new technologies. This more qualitative evidence needs to be investigated further to develop more quantitative evidence on the merits of these market packages.

5.2.4 Commercial Vehicle Market Packages

The market packages in the National Architecture include those relating to commercial vehicle operations and administration. Services are intended to make commercial operators run more efficiently and in a cost-competitive manner. At the same time, many of the public sector's administrative role in monitoring commerce and goods transportation may also be promoted. The market packages that may provide such benefits include:

- Fleet Administration
- Freight Administration
- Electronic Clearance
- Commercial Vehicle Administrative Processes
- International Border Electronic Clearance
- Weigh-In-Motion

- Roadside CVO Safety
- On-board CVO Safety
- CVO Fleet Maintenance
- HAZMAT Management

The benefits of such market packages, shown in Table 5.2-4, include benefits to shippers, carriers and public sector commerce agencies. From the perspective of a potential shipper, these services enhance the mobility of goods through a number of factors. First, there are direct benefits from reduced delays at ports of entry resulting from the electronic clearance, weigh-in-motion, and CVO safety market packages. These packages allow commercial vehicles to avoid long delays for safety or credentials inspections or weighing. As a result, this could yield direct financial benefits to shippers, as these delays often add considerable uncertainty in the arrival time of shipments. In addition, through the fleet and freight administration packages, a shipper may have confidence in the location and status of the shipment, and also may receive more accurate estimates of shipment pick-up and drop-off times. In this way, the market packages may improve goods mobility.

Table 5.2-4: Likely Benefits of Commercial Vehicle Market Packages

Market Package	Likely Benefits	Context Where Benefits May Accrue
Fleet Administration	• Improvements in vehicle and driver productivity • Increase in loaded miles	• Local and long-haul systems
Freight Administration	• Largely unknown level of benefits	• Hazardous materials and other sensitive cargo
Electronic Clearance	• Reduction or elimination of border clearance times • Reductions in commercial and public administrative costs • Improvements in vehicle and driver productivity	• Highest benefits for long-haul carriers
Commercial Vehicle Administrative Processes	• Significant cost savings for commercial vehicle operators and regulatory agencies	
International Border Electronic Clearance	• Reduction or elimination of border clearance times • Reductions in commercial and public administrative costs • Improvements in vehicle and driver productivity	• Highest benefits for long-haul carriers
Weigh-In-Motion	• Reduction in vehicle weighing times • Reductions in commercial and public administrative costs • Improvements in vehicle and driver productivity	• Highest benefits for long-haul carriers
Roadside CVO Safety	• Reduction in safety inspection times • Reduction in commercial vehicle accidents	
On-board CVO Safety	• Reduction in commercial vehicle accidents	
CVO Fleet Maintenance	• Improvement in vehicle productivity • Reduction in commercial vehicle accidents	
HAZMAT Management	• Faster and more appropriate response to HAZMAT incidents	

The market packages may also provide economic benefit for fleet managers. The fleet and freight administration market packages allow a fleet manager to track vehicle position and cargo condition automatically. This allows for monitoring of fleet status and better control of day-to-day operations, and also allows shippers to know the whereabouts of shipments in real time. The economic advantages of such systems are already in evidence, as private companies such as Federal Express and UPS have developed capabilities for real-time vehicle and shipment monitoring.

The on-board CVO safety market package allows both the vehicle driver and the fleet manager to monitor vehicle and cargo condition, thus allowing prevention of incidents (reducing costs directly) and faster response to vehicle and cargo hazards. Moreover, delays related to CVO safety inspections at ports of entry may also be reduced through automating some parts of the vehicle and cargo inspection process, as is suggested by the roadside CVO safety market package.

Perhaps the highest level of benefit for commercial vehicle fleet managers and operators is found in the electronic clearance and international borders electronic clearance packages. For the vehicle, it allows electronic transfer of credentials at designated ports of entry, thereby reducing or eliminating the delays that occur when this process is done manually. This market package also supports electronic filing of credentials with governmental agencies, again saving manual effort and costs associated with performing these tasks manually. While there seem to be economic advantages of such electronic clearance market packages, there has only been limited trials of these systems to date.

Finally, benefits may also appear to public agencies in the form of improved and automated processing of CVO credentials, weighing, safety inspection, etc. By performing such tasks automatically through electronic means, there may be significant efficiencies introduced to the administration, enforcement and regulation of commercial vehicles.

5.2.5 Vehicle Safety Market Packages

Advanced vehicle safety systems offer the opportunity to assist, and in some cases automate, many of the driving tasks. In this regard, many of the AVSS market packages have considerable implications for the transportation system performance most generally, and for individual benefits as well. Market packages in the architecture that may be classified as AVSS-related include:

- 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

The benefits of these market packages span both the more obvious safety benefits as well as the benefits from increased transportation system performance. These are discussed in separate sections below and highlighted in Table 5.2-5.

5.2.5.1 Safety Benefits

The first work which estimated the benefits of AVSS devices like those involved in these market packages was made in Britain. The data used was an "in-depth" accident data-bank: the original data on separate accidents was consulted. In the US, conflicting requirements for confidentiality and freedom of information have prevented access to similar data which is collected for the FARS (Fatal Accident Reporting System) and GES (General Estimates System) data banks of NHTSA. Many researchers have argued that the expurgated versions of these data banks do not enable reasonable and precise evaluations of AVSS devices. Other techniques for making such estimates have been proposed, but these do not produce convincing arguments on both theoretical and practical grounds.

Accordingly NHTSA has arranged that certain contractors can view the accident data collected for GES and FARS before it is expurgated and received by NHTSA. These contractors are evaluating the safety impact of all the elements of these services, though

Table 5.2-5: Likely Benefits of Vehicle Safety Market Packages

Market Package	Likely Benefits	Context Where Benefits May Accrue
Vehicle Safety Monitoring	• Lower vehicle maintenance costs • Lower accident and vehicle breakdown rates	
Driver Safety Monitoring	• Lower accident rates due to driver impairment	
Longitudinal Safety Warning	• Reduction in backing and rear-end accidents	
Lateral Safety Warning	• Reduction in lane departure accidents	
Intersection Safety Warning	• Difficult to estimate level of reduction of intersection-based accidents • Some intersection-related accidents may be avoided	• Higher possible value at unsignalized intersections
Pre-Crash Restraint Deployment	• Reduction in accident severity	
Driver Visibility Improvement	• Reduction in accidents due to driver vision impairment • Reduction in night vision impairment accidents	• Higher benefits in night driving, inclement weather • Significant benefits for visually challenged drivers
Advanced Vehicle Longitudinal Control	• Improvement in highway lane capacity • Reduction in rear-end and backing accidents with other automobiles • Reduction in rear-end and backing accidents	• Applications most likely on freeway and other restricted-access roads

	with fixed objects	
Advanced Vehicle Lateral Control	• Reduction in lane departure accidents	• Applications most likely on freeway and other restricted-access roads
Intersection Collision Avoidance	• Unknown level of benefits, difficult to quantify	• Possible high value at unsignalized intersections
Automated Highway System	• Significant improvements in highway lane capacity • Broad range possible safety and environmental benefits, depending on system design	• Likely scenarios still under discussion

the categorization adopted by NHTSA is not identical with that contained in the user service descriptions in Attachment #6 of the IVHS Systems Architecture RFP or in the Joint Team's market packages. A list of these projects and their areas of study is given in Table 5.2-6.

Table 5.2-6: Relevant NHTSA-Sponsored AVSS Research

Area of Research	Related Market Packages
Rear-end Collisions	Longitudinal Safety Warning Advanced Vehicle Longitudinal Control
Backing Crashes, Lane Changes	Longitudinal Safety Warning Lateral Safety Warning Advanced Vehicle Longitudinal Control Advanced Vehicle Lateral Control
Road Departures	Longitudinal Safety Warning Lateral Safety Warning Advanced Vehicle Longitudinal Control Advanced Vehicle Lateral Control
Intersection Collision Avoidance	Intersection Safety Warning Intersection Collision Avoidance
Pre-crash Restraint Deployment	Pre-crash Restraint Deployment

The Joint Team believes that any assessment carried out without access to this or similar data, will necessarily be inferior to the reports of the NHTSA contractors, which are now available. A summary and critique of the results of these studies will appear in subsequent versions of this document. In addition, there are two areas, head-on collisions/passing and vision enhancement, that are not yet the subject of NHTSA contracts. However they do need to be tackled by the same techniques, and the same problems of access to data will arise. Furthermore, research currently being carried out as part of the National Automated Highway Systems Consortium (NAHSC) will also be reviewed as it becomes available, but the schedule of the NAHSC may preclude such results from being included in the Architecture results.

5.2.5.2 Transportation System Benefits

In addition, several of the AVSS market packages may impact road network capacity and driving behavior more substantially, including:

- Advanced Vehicle Longitudinal Control
- Advanced Vehicle Lateral Control
- Intersection Collision Avoidance
- Automated Highway Systems

There is a growing body of research into these types of services, particularly with the advent of the National Automated Highway System Consortium (NAHSC). This research suggests that more considerable gains in roadway capacity could be gained through these types of market packages. That is, by automating the driver's steering, braking, and throttle control functions, there may be more efficient car following and maneuvering behavior, with resulting increases in effective road capacity.

It is important to understand that the results to date are based solely on mathematical analysis and simulation. As such, the benefits are highly uncertain and are subject to considerable assumptions about driver behavior and safety impacts. There is also no empirical evidence to date to support these improvements, and these benefits are likely to be realized much later in the future (more than 10 to 20 years from now).

Longitudinal control systems would seek to improve the use of existing roadway capacity by automatically maintaining vehicle spacing. Under an automated highway system, it is estimated that road capacity could be improved by two to three times the current capacity (i.e., 4000 to 6000 vehicles per hour), also at somewhat higher average speeds. As such, individual drivers would realize benefits from either (1) increased speeds or (2) accommodation of more vehicles on (presumably faster) freeways. There are thus a high level of potential individual mobility benefits that could be achieved through vehicle control market packages.

These improvements thus have considerable implications for the transportation system as a whole. In effect, these capacity improvements will have at least the following two benefits for the transportation system as a whole:

- Average speeds may be increased through automating some of the driving functions, thus effectively reducing current network travel times;

- With the available capacity, more travel may occur, in the form of induced demand, providing additional mobility benefits. The direct impacts in the transportation system are an obvious direct increase in VMT.

In the latter case, such increases in VMT have significant implications for fuel consumption and vehicle emissions in the transportation system: one may easily believe that vehicle emissions and fuel usage would also rise by similar proportions. The amount of induced demand caused through such radical increases in capacity are still being investigated. Nonetheless, these types of impacts must be carefully weighed in considering deployment of these market packages. Deployment decisions by local transportation policy-makers and planners may wish also to consider:

- Deployment decisions for these market packages, particularly AHS, must be made within the context of a broader local or regional transportation policy and planning perspective. This perspective ensures that the policy goals of a particular geographic area can be evaluated and addressed before these market packages are deployed.

- The architecture itself supports market packages that can be deployed to mitigate adverse mobility and environmental impacts, through ITS-related services in: demand management, traffic management, emissions monitoring and control, and HOV and transit prioritization.

5.2.6 Emergency Management Market Packages

There may be many benefits resulting from improved coordination for emergency response. The National Architecture includes two market packages that address emergency management and response most directly. Other incident management services are included as part of the Traffic Management market packages, described in Section 5.2.2. These are:

- Emergency Response
- Emergency Routing
- Mayday Support

Benefits of these market packages are listed in Table 5.2-7. While the benefits of coordinated emergency response are relatively easy to articulate, very little work to date has been done to quantify these types of benefits. These market packages both allow automated forwarding of emergency calls to appropriate agencies, and may include some information on the location of the emergency. The most obvious benefit, then, would be that the reaction and response time to an emergency call would be reduced, resulting in faster action to address the emergency. In addition, drivers of emergency vehicles may be better aware of the location of an incident, and be more sure of their destination. On the whole, more research is necessary to quantify and support the benefits of implementation of these services.

Table 5.2-7: Likely Benefits of Emergency Management Market Packages

Market Package	Likely Benefits	Context Where Benefits May Accrue
Emergency Response	• Assumed reduction in response times through system-coordinated response	• Higher level of benefit realized in areas with multiple jurisdictions and independent response agencies
Emergency Vehicle Routing	• Unknown level of benefits	
Mayday Support	• Anticipated faster routing of calls, shorter response times	• Higher level of benefit realized in areas with multiple jurisdictions and independent response agencies • High benefits in rural areas

5.2.7 ITS Planning Market Package

Finally, the National Architecture includes an ITS Planning market package to facilitate coordinated ITS planning and deployment. At its broadest level, this market package allows local ITS implementors and transportation decision-makers to consult a common set of information about ITS and associated technology implementations. For planning purposes, this information can lead to more effective ITS research, development, planning and implementation. Additional guidance on the role of the architecture in ITS planning is included in the *Implementation Strategy* document. These benefits are summarized in Table 5.2-8.

Table 5.2-8: Likely Benefits of ITS Planning Market Package

Market Package	Likely Benefits	Context in which Benefits May Accrue
ITS Planning	• Largely unknown level of benefits; rarely measured in quantitative terms • Potential reduction in effort required for data collection and analysis for system planning • Coordinated system planning may yield more efficient use of funding and other resources	• Institutional relationships at a regional level must be sufficient to facilitate cooperation between different agencies and jurisdictions

One advantage of the integration of a broad range of services in the National Architecture is that it will provide early planning information in its deployment. That is, in its early deployment, the architecture will provide a substantial amount of information about the operation of the transportation system. For both technical and functional purposes, architecture depends upon early deployment of several surveillance-related market packages:

- Network Surveillance
- Probe Surveillance
- Virtual TMC and Smart Probe
- Transit Vehicle Tracking
- Fixed-Route and Demand-Responsive Operations (Transit)
- Vehicle Tracking and Dispatch (CVO)
- Emergency Response

These market packages provide the corresponding organization with a significant amount of information about the state of the transportation system, including its daily operation and its evolution over time.

The availability of this information may have significant benefits for transportation planning most generally, and even for evaluation and evolution of ITS. The data on vehicle operations, traffic flows, incident patterns, etc. can be used to great advantage for a number of purposes, such as:

- Understanding existing transportation problems;
- Understanding and evaluating local and region-wide transportation demand patterns;
- Evaluating the effectiveness of ITS services in meeting regional and national transportation policy goals;

- Providing a rich database of experience from which to plan for the development of future transportation system improvements; and,
- Improving research and analysis of transportation problems.

For these reasons, there are benefits to initial deployment of surveillance-based market packages, and feel that the richness of data and information so provided will significantly enhance the state of the practice for both ITS and more traditional transportation evaluation and planning.

5.2.8 Benefits Accrual

The allocation of benefits and costs among stakeholder groups integrates the results of the benefits assessment and cost analysis. A single benefit/cost accrual matrix offers a useful reference tool for potential implementors of the ITS market packages. The ITS user services cover a wide array of surface transportation technologies, and therefore offer the opportunity to positively affect the overall efficiency of the entire network. When policy makers examine the impacts of implementing the ITS market packages, which may potentially alter the allocation of resources among stakeholders; benefit/cost analysis provides a meaningful purpose.

In a benefit/cost study, the actual gains and losses from a policy are listed, quantified when possible, and compared. In this case, the ITS goals have been stated, the metrics which define the goals have been listed and will be quantified or defined qualitatively, and then compared to the cost of each service package.

In order to identify the way in which ITS benefits accrue, the stakeholder groups affected by the deployment of the ITS market packages must be identified. In general, there are four groups of potential beneficiaries - society, the government, industry, and individuals. However, these categories must be further defined in order to produce greater understanding of the impacts of ITS deployment. Therefore the stakeholder groups used in this study include: society, traffic management centers, transit management centers, emergency management centers, fleet managers, fleet drivers, individuals driving privately-equipped vehicles, individuals driving non-equipped vehicles, and transit and HOV users. Having identified the relevant stakeholder groups, the next step is to designate to whom the direct and indirect benefits of each market package accrue. This is shown in Table 5.2-9.

In this table, there are some fairly interesting results. Within the ATIS market bundle, we observe that the direct beneficiaries are those who have purchased or who have access to ATIS equipment. As was noted in Section 5.2.1, however, unequipped drivers may also experience benefits, resulting from the changes in travel patterns when equipped drivers change departure time, mode or route in response to information. The general pattern, however, suggests that those who receive the direct benefits of these services will be those who make the decision to purchase this ATIS equipment.

For the ATMS market bundle, the benefits fall among a broad range of the traveling public. All roadway travelers receive benefits of enhanced traffic management, but only HOV and transit travelers will receive benefits from HOV lane management and other demand management measures. However, for the most part, these last two market packages are intended to divert travelers into higher-occupancy modes, and thus enhance

Table 5.2-9: Benefits Allocation of ITS Market Packages

MARKET PACKAGE	SOCIETY	TRAFFIC MANAGEMENT CENTER	TRANSIT MANAGEMENT CENTER	EMERGENCY MANAGEMENT CENTER	FLEET MANAGERS	FLEET DRIVERS	EQUIPPED TRAVELERS	UNEQUIPPED TRAVELERS	TRANSIT & HOV USERS
Broadcast-based ATIS							Direct	Indirect	
Interactive Traveler Information							Direct	Indirect	
Autonomous Route Guidance							Direct	Indirect	
Dynamic Route Guidance							Direct	Indirect	
ISP Based Route Guidance							Direct	Indirect	
Integrated Transportation Management/Route Guidance							Direct	Indirect	
Yellow Pages and Reservation							Direct	Indirect	
Dynamic Ridesharing							Direct	Indirect	Direct
In Vehicle Signing							Direct		
Network Surveillance	Indirect	Direct					Indirect	Indirect	Indirect
Probe Surveillance	Indirect	Direct					Indirect	Indirect	Indirect
Surface Street Control		Direct					Indirect	Indirect	Indirect
Freeway Control		Direct					Indirect	Indirect	Direct
HOV and Reversible Lane Management		Direct					Direct	Direct	Direct
Traffic Information Dissemination	Indirect	Direct					Direct	Direct	Direct
Regional Traffic Control	Indirect	Direct					Indirect	Indirect	Indirect
Incident Management System	Indirect	Direct	Direct				Direct	Indirect	
Traffic Network Performance Evaluation	Indirect	Direct					Indirect	Indirect	Indirect
Dynamic Toll/Parking Fee Management	Indirect	Direct					Direct	Indirect	
Emissions and Environmental Hazards Sensing	Indirect	Indirect					Direct	Indirect	
Virtual TMC and Smart Probe Data	Indirect	Direct					Direct	Indirect	

Table 5.2-9: Benefits Allocation of ITS Market Packages (Continued)

MARKET PACKAGE	SOCIETY	TRAFFIC MANAGEMENT CENTER	TRANSIT MANAGEMENT CENTER	EMERGENCY MANAGEMENT CENTER	FLEET MANAGERS	FLEET DRIVERS	EQUIPPED TRAVELERS	UNEQUIPPED TRAVELERS	TRANSIT & HOV USERS
Transit Vehicle Tracking			Direct						Indirect
Fixed-Route Operations			Direct						Direct
Demand-Responsive Transit Operations			Direct						Direct
Passenger & Fare Mgmt			Direct						Direct
Transit Security			Direct	Indirect					Direct
Transit Maintenance			Direct						Indirect
Multi-Modal Coordination			Direct						Direct
Fleet Administration					Direct	Indirect			
Freight Administration					Direct	Indirect			
Electronic Clearance					Direct	Indirect			
CV Adminstrative Processes					Direct	Indirect			
International Border Electronic Clearance					Direct	Indirect			
Weigh-In Motion					Direct	Indirect			
Roadside CVO Safety					Direct	Direct			
On-Board CVO Safety			Indirect		Direct	Direct			
CVO Fleet Maintenance					Direct				
HAZMAT Management		Direct			Direct				
Emergency Response	Indirect			Direct			Direct	Direct	
Mayday Support				Direct					
Emergency Routing	Indirect			Direct			Indirect	Indirect	
Vehicle Safety Monitoring							Direct		
Driver Safety Monitoring							Direct		
Longitudinal Safety Warning							Direct		
Lateral Safety Warning							Direct		
Intersection Safety Warning							Direct		
Pre-Crash Restraint Deployment							Direct		
Driver Visibility Improvement							Direct		
Adv. Longitudinal Control							Direct		
Adv. Lateral Control							Direct		
Intersection Collision Avoidance							Direct		
Automated Highway System							Direct		
ITS Planning	Indirect								

traffic flow by increasing mobility. Because they are designed to support existing traffic management functions, the traffic prediction market package and the probe vehicle infrastructure market package provide direct benefits to traffic managers. Yet, the information thus gained will be used to benefit all travelers, and especially those who may use such information in ATIS services. Toll plaza operations benefits those who are equipped; the likely low cost of equipment leads us to believe that the number of equipped travelers will be considerably larger than those for the more expensive ATIS devices.

The APTS market packages, as might be expected, yield direct or indirect benefits for transit users and the transit management center. In all cases, however, the primary beneficiary includes the transit agency itself. This may indicate that transit users will not perceive direct benefits from many of these market packages, even though the transit agency is enhancing its own service delivery.

Commercial vehicle operators, in the form of fleet managers and drivers, receive significant benefits from the market packages in the CVO market bundle. Fleet managers are the direct beneficiaries of all market packages, as their operations may be streamlined through automation of many management and administrative tasks. Likewise, fleet drivers may also receive indirect benefits from all four market packages, as their driving is subject to less delay at ports of entry and inspection facilities and as they receive additional support from fleet managers through routing and dispatch. Shippers also receive indirect benefits through more timely arrival of shipments and improved tracking and safety of goods that are shipped. Government regulators also receive direct benefits, as their administrative work is reduced through electronic filing of credentials, safety inspection, and weigh-in-motion capabilities at roadside facilities.

The emergency management market packages provide direct benefits to the emergency management center, through automating emergency response. More directly, the emergency response market package has direct benefits for travelers involved in incidents, and also results in indirect benefits to society at large as there can be faster response to emergencies. Finally, and perhaps most obviously, the safety benefits of the AVSS market packages will accrue to those whose vehicles are equipped.

The accrual of benefits identified in Table 5.2-9 has some clear implications for the National Architecture. First, in many cases it is relatively easy to identify direct beneficiaries who may bear the costs of these market packages directly. For the ATIS and AVSS market bundles, the benefits accrue to those who have the requisite equipment for each market package. Thus, one might expect that those individuals who receive the benefits will also be the ones who pay for them, through their purchase and operation of this equipment.

A similar argument could also be made for the CVO and APTS market bundles. In these cases, the most obvious direct beneficiary is the fleet manager and transit agency, respectively. These organizations may also be expected to purchase these market packages directly, and then pass these costs on to their customers (the indirect beneficiaries). The equity of this allocation of costs to transit passengers by a (likely public sector) transit agency may be questionable, however.

For the ATMS and EM market bundles, benefits accrue to all roadway travelers and in many cases to society at large. Benefits also accrue to HOV and transit users, who will receive benefits under a number of the ATMS market packages, but whose choice of mode also enhances broader societal goals of increasing mobility and enhancing system-wide traffic flow. There is an open question about how such market bundles that provide social benefits (ATMS, APTS, and EM) may recover costs in an equitable manner. However, the architecture does support pricing mechanisms, through the demand management market package, that may be used to allocate costs equitably among system users as they pay for their system use (e.g., through electronic payment capabilities for tolls, transit fares, parking, etc.).

5.3 Connecting Market Packages, Benefits and ITS Goals

In this section, we present a summary of our evaluation of the National Systems Architecture as it impacts the overall goals of ITS. This summary discusses the direct linkages between the market packages and the six goals stated in the Team's *Mission Definition* document:

1. Increase Transportation System Efficiency and Capacity
2. Enhance Mobility
3. Reduce Energy Consumption and Environmental Costs
4. Improve Safety
5. Increase Economic Productivity
6. Create an Environment for the ITS Market

This discussion connects the benefits of the Team's market packages, from the benefits metrics in Section 5.1 to these goals. The argument is also made regarding the ability of the architecture to support these goals.

One element that is important in understanding the National Systems Architecture is that it enables regional, state, and federal transportation policies. This argument follows from our understanding of the role of ITS in enhancing the nation's transportation system and encouraging economic productivity and new ITS-related industries. This orientation was mentioned in the objectives of the benefits analysis in Section 3.1.

In the discussion that follows, we make the case that the National Architecture supports the six goals mentioned above. However, and perhaps more importantly, the architecture supports a regional, state, and federal deployment of the architecture in a manner that is consistent with these larger transportation, economic, social, and political goals. The key to the architecture is its flexibility in its deployment. We expect that public agencies may have different transportation policies and goals, and thus may have different interests in the types of mobility they may want to encourage. As such, each planning agency must seriously consider its goals in the context of existing transportation problems and objectives. Thus, the ability of the National Architecture to achieve any of these six goals will ultimately depend on how local, regional, state, and federal planners and policy-makers choose to deploy the architecture. This is a key point to keep in mind when evaluating the potential deployment of any architecture.

Table 5.3-1 summarizes the connection of market packages to ITS goals. In this table, the number of stars (0 to 3 stars) indicates the relative contribution of each market package to achieving each of the goals. The following narrative summarizes the market packages which should be targeted to address each of the goals.

Table 5.3-1: Benefits of Market Packages for Achieving ITS System Goals

	Market Packages	ITS System Goals: Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
	Transit Vehicle Tracking	*	**	*		*	*
	Fixed-Route Operations	*	**	*		*	*
	Demand-Responsive Operations	*	**	*		*	*
APTS	Passenger and Fare Management					**	*
	Transit Security				**		*
	Transit Maintenance					*	*
	Multi-modal Coordination	*	*			*	
	Broadcast Traveler Info	*	**	*			***
	Interactive Traveler Info	**	***	*			***
	Autonomous Route Guidance	**	***				***
	Dynamic Route Guidance	**	***	*	*		***
ATIS	ISP-Based Route Guidance	**	***	*	*		***
	Integrated Transportation Mgmt / Route Guidance	***	***	**	*		**
	Yellow Pages and Reservation		*				**
	Dynamic Ridesharing	**	*	*			*
	In Vehicle Signing		*		*		***
	Network Surveillance	*	*	*			*
	Probe Surveillance	*	*	*			**
	Surface Street Control	**	***	**	**		*
	Freeway Control	**	***	**	*		*
	Regional Traffic Control	***	***	***	**		*
ATMS	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	*	*	*		*	*
	Fleet Administration		***			***	**
	Freight Administration		***			***	**
	Electronic Clearance	**	***			***	**
	CV Administrative Processes					**	*
CVO	International Border Electronic Clearance	**	***			***	**
	Weigh-In-Motion	**	***			***	**
	CVO Fleet Maintenance	*			**	**	*
	HAZMAT Management	*			**	**	*
	Roadside CVO Safety	*	**		**	**	**
	On-board CVO Safety				***	**	**

Key: * = low benefit, ** = moderate benefit, *** = high benefit

Table 5.3-1: Benefits of Market Packages for Achieving ITS System Goals (Continued)

	Market Packages	Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
		ITS System Goals					
AVSS	Vehicle Safety Monitoring				***		***
AVSS	Driver Safety Monitoring				***		***
AVSS	Longitudinal Safety Warning				***		***
AVSS	Lateral Safety Warning				***		***
AVSS	Intersection Safety Warning				***		***
AVSS	Pre-Crash Restraint Deployment				***		***
AVSS	Driver Visibility Improvement				***		***
AVSS	Advanced Vehicle Longitudinal Control	**	*		***		***
AVSS	Advanced Vehicle Lateral Control	**	*		***		***
AVSS	Intersection Collision Avoidance				***		***
AVSS	Automated Highway System	***	***		***		***
EM	Emergency Response	*		*	***	**	*
EM	Emergency Routing	*		*	***	**	*
EM	Mayday Support				***	*	**
ITS	ITS Planning	**	**	**	**	**	***

Key: * = low benefit, ** = moderate benefit, *** = high benefit

5.3.1 Increase Transportation System Efficiency and Capacity

The analysis of benefits has explicitly considered improvements in the effective capacity and improvements in traffic flow over the existing transportation system infrastructure. Section 5.2 identified market packages in the architecture that seem to improve traffic flow, but were also sensitive to the goal of reducing fuel use and enhancing the environment. From that discussion, the market packages from the architecture that potentially provide the highest level of benefits, at least in the short term, include:

- Broadcast Based ATIS
- Interactive Traveler Information
- Autonomous Route Guidance
- Dynamic Route Guidance
- ISP Based Route Guidance
- Integrated Transportation Management/Route Guidance
- Surface Street Control
- Freeway Control
- Traffic Information Dissemination
- Regional Traffic Control
- Incident Management System

Alone, each of these market packages hold out the benefits in the form of reduced network travel and delay times, reductions in the number of stops, and only small increases in VMT. These market packages provide what seem to be the largest possible gains in transportation system efficiency in the short run from early deployment (in the 5- to 10-year time frame).

These gains in system-wide traffic flow may have considerable implications for induced demand in the travel network. For this reason, we believe that the architecture must be deployed in a manner that is consistent with local transportation planning and policy objectives. Moreover, we believe that the architecture can be used to support management of demand, including effects on air quality and the environment (as discussed in Section 5.3.3).

5.3.2 Enhance Mobility

Individual, corporate, and system-wide mobility embodies enhancements in terms of traveler information and service enhancements to affect travel-related choices. The quantitative benefits of mobility, both from the perspective of individual and system-wide mobility, have been discussed in Section 5.2. That analysis suggested that many of the market packages proposed within the Joint Team’s architecture can provide individual travel time benefits. Market packages that support this level of individual benefits include:

- Broadcast Based ATIS
- Interactive Traveler Information
- Autonomous Route Guidance
- Dynamic Route Guidance
- ISP Based Route Guidance
- Yellow Pages and Reservation
- Integrated Transportation Management/Route Guidance
- Surface Street Control
- Traffic Information Dissemination
- Regional Traffic Control
- Incident Management System

Such mobility enhancements suggest a final set of market packages that provide better information on travel alternatives and enhancing the utility of non-SOV travel. This more expansive view of mobility leads to the following possible list of market packages as providing a high level of mobility benefits:

- Broadcast Based ATIS
- Interactive Traveler Information
- Autonomous Route Guidance
- Dynamic Route Guidance
- ISP Based Route Guidance
- Integrated Transportation Management/Route Guidance
- Surface Street Control
- Traffic Information Dissemination
- Regional Traffic Control
- Incident Management System
- HOV and Reversible Lane Management
- Transit Vehicle Tracking
- Transit Fixed-Route Operations
- Transit Demand-Responsive Operations

This set includes not only the market packages that suggest more significant benefits, but also includes market packages that enhance mobility through higher-occupancy travel modes, including HOV and transit use. Still, most of these market packages have quantifiable benefits to the traveler, primarily in terms of potential time savings and the resulting improvements in accessibility.

5.3.3 Reduce Energy Consumption and Environmental Costs

The improvements to the transportation system have been described qualitatively in Section 5.2. While there is yet little empirical evidence of the ability of ITS user services to reduce energy use and enhance the environment, there are several proxy variables that suggest that many of the market packages will enhance system-wide performance in these areas as well. Most directly, the National Systems Architecture includes market packages for area-wide traffic management and for emissions and environmental monitoring. Even just by knowing the magnitude and geographic scale of air quality problems, traffic may be better managed (through routing and traffic control measures) to reduce emissions in certain areas. Thus, the emissions and environmental sensing market package may be implemented most directly to monitor and influence environmental conditions, depending on the types of system control measures that may used in response.

In addition, those market packages that were seen to provide quantifiable benefits to traffic flow, and thus to fuel consumption and air quality, include:

- Broadcast Based ATIS
- Interactive Traveler Information
- Autonomous Route Guidance
- Dynamic Route Guidance
- ISP Based Route Guidance
- Integrated Transportation Management/Route Guidance
- Surface Street Control
- Freeway Control
- Traffic Information Dissemination
- Regional Traffic Control
- Incident Management System

By routing traffic around congested parts of the network, and through better management of existing travel patterns and incidents, travel times in the network can be reduced. Each of the factors of higher speeds and a reduction in accelerations and stops suggests that vehicle emissions and fuel consumption would be reduced. While there is little quantitative research to date that confirms the magnitude or even direction of these impacts, there is at least a growing body of researchers that support this conclusion on qualitative grounds.

5.3.4 Improve Safety

The preliminary qualitative and quantitative analysis of safety benefits of the National Systems Architecture and its corresponding market packages suggest that there are significant safety benefits that can be addressed through ITS. Possible market packages that could be early and likely big winners from the point of view of safety benefits include:

- Roadside CVO Safety
- On-board CVO Safety
- HAZMAT Management
- Mayday Support
- Transit Security
- Emergency Response
- Emergency Routing
- Incident Management System
- Vehicle Safety Monitoring

In the above description of benefits, there are clear advantages to these market packages. Generally, as one might expect, safety benefits are likely to be realized through prevention or early detection of hazardous situations, speedier notification of incidents and emergency situations, and faster response to incidents and other travel-related emergencies. In such cases, significant improvements in vehicle safety seem possible, and are likely to be technically feasible in the short term (5-10 years). The benefits of more vehicle-based safety systems (others in the AVSS market bundle) are still uncertain at this time; however, further investigation of these technologies and their capabilities may give additional insight into the timing and likely benefits of these market packages. In any case, the more advanced vehicle safety market packages are not likely to be implemented in any significant way before at least the 10-year time frame (2002).

The safety benefits may also be considered directly from the features of the architecture itself. A preliminary hazard analysis of the 29 user services conducted as part of the Phase I analysis has identified several hazards that we believe are important to our architecture development, including:

1. The risks of serious technical hazards with several of the advanced vehicle safety systems market packages (e.g., automated highway systems, intersection collision avoidance, etc.). This includes the ability of the architecture's functions to degrade gracefully and safely with these market packages

2. The need for good design of major systems (e.g., traffic management and signal control functions).

3. The need for security and integrity in transmitted messages within the architecture.

The National Architecture incorporates reasonable mitigation approaches to these issues. In response to the first item, our preliminary architecture definition for the AVSS market bundle emphasizes vehicle-based functionality, and thus minimizes the need for critical external interfaces. As for the second point, the critical systems design issues are based on potential deployments of the architecture. To this end, we have included important design criteria in our development of the architecture's performance requirements, in Section 4 of the *Mission Definition* document, and in the guidance proposed in the *Implementation Strategy* document. Finally, the Joint Team's approach to information integrity and security address the criticality of communications links. Our analysis of these issues, and our treatment of these security and integrity issues, is described in greater detail in Section 2.2.7, describing the technical performance of our architecture with respect to security safeguards.

5.3.5 Increase Economic Productivity

One of the stated goals of the ITS program is to improve economic productivity. Certainly one perspective on improving economic productivity involves providing individual users as well as public and private agencies with a more effective and cost-efficient means of doing business. The National Systems Architecture supports a broad range of market packages that contain this feature, primarily through automating processes that are now conducted manually, or also by improving the flow of information within the transportation system.

5.3.5.1 Market Packages that Increase Economic Productivity

There are many market packages within the architecture to improve personal and corporate productivity. First, in terms of financial transactions, the architecture supports several packages to enhance and automate financial transactions for transportation services. This may take the form of a debit or smart card to pay for services electronically, or setting up an account with a service provider that is debited (or credited) whenever the system is used. As such, the architecture reduces the cost of manual collection and cash handling. We believe there are substantial financial savings that may be realized here, as evidenced by the development of billing support services, smart cards, and debit cards in other (non-transportation) industries. Within the architecture, the market packages that support this function include:

- Dynamic Toll/Parking Fee Management
- Passenger and Fare Management

Other market packages seek to automate service delivery, or simply reduce the administrative costs of various transportation functions. For emergency management systems, the emergency response and mayday support market packages reduces the level of manual handling of emergency calls by providing geographic referencing for incoming calls and forwarding of messages automatically to appropriate personnel. For commercial vehicle operations, the Joint Team’s market packages are designed to provide economic benefit for fleet managers. Market packages in this area include:

- Fleet Administration
- Freight Administration
- Electronic Clearance
- Commercial Vehicle Administrative Processes
- International Border Electronic Clearance
- Weigh-In-Motion
- CVO Fleet Maintenance

The fleet administration and freight administration market packages allow a fleet manager to track vehicle position and cargo condition automatically. This allows for monitoring of fleet status and better control of day-to-day operations, and also allows shippers to know the whereabouts of shipments in real time. The economic advantages of such systems are already in evidence, as private companies such as Federal Express and UPS have developed capabilities for real-time vehicle and shipment monitoring.

The CVO safety market packages allows both the vehicle driver and the fleet manager to monitor vehicle and cargo condition, thus allowing prevention of CVO incidents (reducing CVO cost directly) and faster response to vehicle and cargo hazards. Moreover, delays related to CVO safety inspections at ports of entry may also be reduced through automating some parts of the vehicle and cargo inspection process.

Perhaps the highest level of benefit for commercial vehicle fleet managers and operators is found in the electronic clearance market packages. For the vehicle, it allows electronic verification of credentials at designated ports of entry, thereby reducing or eliminating the delays that occur when this process is done manually. Delays associated with vehicle weighing may also be reduced by weigh-in-motion capabilities of the weigh-in-motion market package. This market package also supports electronic filing of credentials with governmental agencies, again saving manual effort and costs associated with performing these tasks manually.

Similar cost and personal productivity improvements may be realized within the transit industry through the APTS market packages:

- Transit Vehicle Tracking
- Fixed-Route Operations
- Demand-Responsive Operations
- Passenger and Fare Management
- Transit Maintenance

The passenger and fare management and transit vehicle tracking market packages provide real-time information to improve transit service. By collecting passenger load and vehicle location information automatically, this reduces the need for manual data collection and increases the accuracy of this data. Moreover, the availability of this data allows for improved service planning, thereby enhancing the job of making transit service more cost-effective and efficient. Costs associated with service planning and maintenance planning may be reduced by automating the routing and scheduling of services. In addition, electronic vehicle tracking and vehicle condition monitoring (in the transit vehicle maintenance market package) allow for reduced manual collection of such information in the field, thereby reducing labor costs.

5.3.5.2 Architecture Features that Enhance Economic Productivity

There are several features of the National Systems Architecture that enhance the level of economic productivity. First of all, the architecture provides inter-operability. Thus, for most of the market packages described above, there will be standard interfaces across the United States so that individuals and firms that use ITS products and services can use them across the country. For electronic payment services, this means that a toll tag or smart card that works in Boston can also be used in New York, or all the way across the country in Seattle. For commercial vehicles, national inter-operability implies that these long-haul carriers can travel across the country using the same devices for vehicle-to-roadside communications, including communications with their fleet management center and also with roadside inspection and roadside clearance facilities.

One other aspect of inter-operability that also appears in the architecture is a commonality of communications systems, allowing a seamless communications system that may perform any number of tasks. The wide-area communications system may be used for both data and voice messages, and accommodates a broad range of market packages. This ensures that many different functions can be accommodated within a single wide-area communications system and interface. Also, the communications systems proposed for the vehicle-to-roadside communication in the architecture may use a common communications infrastructure for many different functions, such as toll payment, CVO clearance, etc. For example, the long-haul truck can use a single communications infrastructure to pay their toll at an electronic payment facility, but also to communicate vehicle credentials to a roadside facility at a state line. This commonality of the short range vehicle-to-roadside communications interface means that users do not have to buy different devices and systems to provide the same communications capability.

The other advantage of the architecture is that it provides a modular system with multiple levels of market package functionality. The advantage of this capability for economic productivity is two-fold: (1) benefits may be realized from a small investment, and (2) the capabilities of a package or set of packages may grow incrementally as an individual or organization is likewise able to grow in their means, but with compatibility with existing systems. Economically, this means that the ITS market packages are accessible to a the broadest possible range of potential users. The market size is thus larger, with a corresponding large set of ITS system beneficiaries.

5.3.6 Create an Environment for an ITS Market

One of the goals for the development of an ITS systems architecture is that it provide the proper stimulus to encourage the initiation of new (ITS-related) industries. The National Systems Architecture has several features to enhance the growth of an ITS industry. This section describes the capability of the architecture to enhance the development of this industry.

First, the National Architecture emphasizes flexibility and openness. These words have specific meaning for the development of new products. First, all components of the architecture are non-proprietary. This means that the number of potential firms that may enter the ITS market is not limited by the definition of the architecture. Thus, any number of firms may enter the market for devices, for communications systems, for hardware and software, etc. Second, the architecture is also flexible, which in this context means that we expect devices to be compatible to an interface, but what goes on behind the interface is not touched. A firm may have a special product or service it is willing to offer, and the only restriction placed on that firm is that it has the appropriate interfaces to other subsystems in the architecture. This specification of interfaces, but not the internal workings of each architecture subsystem, means that there is ample opportunity for innovation in product and service design.

Second, the architecture is modular and expandable. The equipment packages and market packages described in the architecture may be implemented in a modular and expandable fashion. The specification of key interfaces guarantees that any product or service that is developed is 100% compatible with other systems and technologies in the architecture. Again, the architecture does not specify technologies or the detailed design of functions; rather, it simply assures that any technologies that are so developed are compatible with other parts of the architecture. To a device or service supplier, this ensures that their end product will work with other systems.

In a similar light, the Joint Team's architecture supports multiple levels of functionality and multiple levels of technical sophistication. In terms of functionality, a firm interested in providing a device or service has several options for the level of functionality of that device or service. For example, in the realm of traveler information services, a firm may market a simple paging device that allows the user to access broadcast traffic information. Another firm could market a device that not only receives that information, but allows the user to query for particular pieces of information, allowing greater user interaction. Both levels of functionality are covered in the architecture. Thus, a firm entering the ITS industry has a wide variety of possible ways to enter the market, depending on the chosen level of function and technical sophistication.

Finally, as has been mentioned previously, the architecture will specify interfaces between subsystems; indeed, this specification of interfaces is one of the main purposes of a physical architecture. The level of detail to which these interfaces are specified is also an important piece of the National Architecture. If an interface is over-specified, it may restrict the development of the market for products and services designed to that interface. On the other hand, if an interface is not specified, then particular hardware and software may not be compatible with other systems. The specification of interfaces is described in greater detail in the *Implementation Strategy*, the *Standards Development Plan*, and the *Standards Requirements* documents.

Chapter 6
Summary and Conclusions

This chapter summarizes the analysis of the technical performance and benefits of the National Systems Architecture. While each of these analyses are important independently, it is also true that they form an integrated package that describes what is important and valuable about a national ITS architecture most generally but also about the specific features of the proposed Joint Team's architecture. The benefits achieved by such an architecture are derived from its operation and the technical and functional capabilities the architecture provides; the operations performance measures are driven by the need to produce the highest possible level of benefits. This connection of architecture to benefits is an important link in understanding the purpose and value of the national ITS architecture effort.

The chapter begins by summarizing the technical features and performance of the proposed architecture. These performance measures are further subdivided into system-level performance and operational performance analysis. Section 6.2 concludes this document by presenting the benefits of the architecture; first as a function of the architecture features directly and then also as a function of the market packages that the architecture will provide.

6.1 Summary and Conclusions from Technical Performance Analysis

For the technical performance analysis, we summarize the architecture's technical features into two categories: system performance and operational performance. Within each of these two categories, the results of the performance analysis are presented based on the evaluation criteria given by the government in Attachment #5 of the contract. These results and conclusions are presented in Sections 6.1.1 and 6.1.2, respectively.

6.1.1 System Performance

The analysis of the architecture's technical performance may be summarized using the evaluation criteria provided by the FHWA, and is shown in Table 6.1-1. This table presents a qualitative measure of the performance as well as a justification, summarizing the primary systems-level features of openness and flexibility found in the National Architecture. These systems-level descriptors of the architecture reflect an underlying philosophy that a national IVHS architecture should retain the maximum level of flexibility so that a single specification may support deployments which will differ markedly across time and geographic regions, according to local preferences.

As noted in the table, the Joint Team's architecture provides support for each of the 29 user services suggested by the FHWA. While the description of the architecture is more suitable to the concept of "market packages," these market packages also are traceable to the user service definitions and process specifications. From an analysis of the architecture's evolutionary deployment strategy, the Joint Team's vision for the architecture includes implementing most of the market packages within the 20-year time frame; one exception could be the AVSS market packages which still have considerable technical and institutional issues to overcome before they may be implemented.

The modular and incremental design of the market packages, and the underlying off-the-shelf aspect of the cost packages, also implies that the architecture is open (non-proprietary), flexible and expandable over time and geography. These characteristics of the architecture also justify the claim that the architecture supports a broad variety of levels of system functionality (particularly within the ATIS, ATMS, and AVSS market packages), and allows for a broad range of beneficial in-vehicle equipment for (private) vehicle users.

Finally, we believe the National Architecture has many salient features that will assist in its deployment. First, the architecture leverages existing communications systems capabilities. This is perhaps most obvious in the selection of a cell-based wide area mobile communications service, in which technologies like CDPD are already beginning to mature. These types of communications technologies also have the advantage that the communications infrastructure exists and will continue to exist, largely independent of the development of mobile communications from ITS.

We are also aware, however, that the specification of certain communication or information standards has its advantages and disadvantages. Because one of the goals of the ITS architecture development program is to ensure national inter-operability, we have taken steps to identify the types of interfaces where standards are required or may simply be recommended. However, as much as possible, the architecture avoids specification of interfaces where they are not directly necessary for inter-operability. The main exception here is that while the architecture can be applied based on existing institutional and jurisdictional relationships, we anticipate a need for standards in these interfaces to facilitate information sharing through commonalties in information.

Table 6.1-1: Summary of Systems Performance Criteria

Performance Criteria	Description
Support for ITS User Services	• Physical architecture and market packages provide traceability to the process specifications in the User Service descriptions • Medium to high level of deployment anticipated for non-AVSS user services across all scenarios by 20-year horizon
Flexibility and Expandability	• Open architecture (No proprietary systems) • Market packages are designed in a modular way, allowing incremental growth in levels of function and technical sophistication
Performance of Variously Equipped Vehicles	• Architecture assigns high degree of autonomy and functionality to the private vehicle for ATIS and AVSS market packages • Support for range of products and services at different levels of technical sophistication, and resulting level of travel time and safety benefits
Multiple Levels of System Functionality	• Several market packages with a common purpose but differing levels of function and technical capabilities; e.g. in ATIS and ATMS • Support for range of products and services at different levels of technical sophistication
Incremental Installation: Evolutionary Implementation	• Use of existing wide-area and short-range communications technologies suggests early implementation of many market packages • Deployment strategy considers technical dependencies and likely time frame for evolution and maturity of emerging (but necessary) technologies
Incremental Installation: Existing Infrastructure	• Maximal use of existing, mature technologies, especially through use of cell-based communications for wide-area mobile communications and emerging standards for short-range mobile communications • Emphasis on cooperative information sharing and joint information / database management between institutions • Support of standards to achieve interoperability where necessary (e.g., short range vehicle-to-roadside communications) and/or in support of jurisdictional/institutional cooperation • Avoid specification of standards for internal functions and processes

6.1.2 Operational Performance

The focus to date in the national ITS architecture program has been on systems, rather than operational, performance. This has led to specification of an architecture that has as its primary features flexibility, modularity, and leveraging of existing infrastructure as much as possible. On the more operational end of the architecture, the Joint Team has fleshed out a number of possible deployment options that are consistent with the broad architecture framework. Using tools such as traffic and communications simulation, it is possible to better understand many of the issues and operational requirements of the architecture implementation.

From this examination of deployment options, an evaluation of the operational performance of the architecture was performed. The results of this analysis are shown in Table 6.1-2. In the table, each of the evaluation criteria given by the FHWA is evaluated. The first criterion, accuracy of traffic prediction models, seems to be dependent on the architecture primarily through data collection; that is, inasmuch as data to support traffic prediction will be collected and processed to provide travelers and traffic managers with real-time traffic information. In this regard, the architecture specifies a market package for cooperative probe vehicle data reporting. As for information processing and efficient algorithms for traffic prediction, we feel that these areas are maturing rapidly, and there are no restrictions in the architecture that would limit the software or hardware used for such purposes.

The criteria of efficiency of traffic monitoring and control and the efficiency of the TMC (traffic management center) are related, inasmuch as the primary role of the TMC is in traffic monitoring and management. Candidate designs for TMCs in Urbansville suggest that there will be little difficulty in collecting and disseminating information over a wireline network.. Moreover, it is possible to process traffic information in a relatively short period of time, perhaps with delays on the order of 30 to 60 seconds to have information in a form that can be used for updating control measures (although such frequency is not necessary in practice). Within the architecture, the critical issues for these performance criteria include those of information management and database operations within the TMC.

In terms of accuracy of position location, the National Architecture supports a wide variety of technologies, from satellite and terrestrial trilateration to more simple functions that include fixed position referencing. In addition, as many of the AVSS market packages are very sensitive to position location and very precise object identification, we are continuing to examine the capabilities and types of technologies available.

The two criteria of effectiveness of information delivery methods and adequacy of communications system capacity vis-a-vis expected demand reflect concerns about the delay, throughput, and link capacity of the underlying communications layer of the architecture. Our preliminary analysis of cell-based (wireless) wide area communications suggests that the likely delays in transmission are small, on the order of 0.5 seconds one-way or about 1 second for the forward and reverse links. With a data query time of 1 to 2 seconds at a management center data base, the total information retrieval time to the mobile user would be 2 to 3 seconds. Adequacy of capacity with respect to demand is evidenced by the possibility of dynamically allocating additional cell-based system capacity from voice to data. Simulation results suggest that communications delays can be reduced to about 0.1 to 0.2 seconds (one-way).

There are many other performance requirements of the communications and information management systems in the architecture. In terms of information security, the Joint Team advocates encryption for message encoding where necessary. The need for both user authentication as well as for user privacy of data will impact the level of security for and access to data bases and messages within the architecture. Also, in terms of map update, cost and communications system loads lead the Joint Team to advocate updates of map databases in off-peak times, but the architecture is sufficiently flexible to allow both wireline and wireless updates (although the latter will likely be prohibitively expensive).

Finally, much of the system reliability and safety issues have been examined in terms of a preliminary hazard analysis of the user services that was conducted in Phase I. That preliminary hazard analysis suggests that these issues are likely to be insensitive to the particular architecture itself, but instead will be very sensitive to service and product design.

Table 6.1-2: Summary of Operational Performance Criteria

Performance Criteria	Description
Accuracy of traffic prediction models	• Market packages support a variety of data collection methods, including cooperative probe vehicles and video (CCTV) imaging • Flexibility in design of software for traffic monitoring and prediction
Efficiency of traffic monitoring and control Efficiency of TMC	• Sufficient wireline capacity to support data collection and aggregation with minimal delay • Sufficient wireline capacity to support inter-jurisdictional and inter-agency information sharing • Sufficient in-house processing power to support real-time information processing (30 to 60 second update cycle)
Accuracy of position location	• Support for broad range of existing positioning technologies (satellite- and terrestrial-based trilateration, fixed point referencing, etc.) • Support for emerging but immature high-accuracy technologies for AVSS applications
Effectiveness of information delivery methods	• Mobile communications delays of under 0.5 s for one-way transmission using cell-based technologies • Sufficient information retrieval and database management capability to support data queries in real time (1-2 seconds) • Total information retrieval time of 3 seconds for mobile queries

Table 6.1-2: Summary of Operational Performance Criteria (Continued)

Performance Criteria	Description
Adequacy of communications system capacity vis-a-vis expected demand	• Efficient use of available cell-based communications system capacity • Non-dedicated communications channel allows more efficient use of spectrum
Security safeguards	• Support for encryption techniques for communications • Support for user authentication and non-repudiation communications overhead where anonymity is not practical • Support for technologies and messages that preserve user privacy and anonymity • Support use of TCSEC criteria for rating and securing ITS databases
Map update	• Support for map update in off-peak periods using both wireless and wireline technologies; primarily for exception updates • Data loads and cost for wireline and wireless updates are significant
System reliability and maintainability	• Largely a function of system design and deployment conditions (i.e., architecture-independent)
System safety and availability in degraded modes	• Incorporation of systems ensuring data integrity and security • Support for design guidelines for improving safety in degraded mode operation • Minimal specification of architecture for high safety-critical systems that are still being defined (AVSS market packages)

6.2 Summary and Conclusions from Benefits Analysis

In this section, we present a summary and conclusions from the benefits analysis of the National Architecture. Section 6.2.1 summarizes the important features of the architecture itself that have direct implications for the level of benefits that may be achieved. Section 6.2.2 describes the types of benefits and their accrual to different "users" that may be achieved through implementation of the architecture using market packages.

6.2.1 Key Architecture Features for ITS Benefits

In this section, we describe what we see as the features of the underlying system architecture that enhance ITS benefits. In this way, this section presents a summary of the underlying benefits of the National Architecture in the implementation of ITS user services.

First, the national architecture itself provides several advantages to help foster a market for ITS. The architecture itself enhances the ITS market by providing a common platform for systems integration, both at the level of the architecture and at the level of deployment. Perhaps more at the deployment level, the architecture has contributed to developing consensus standards regarding ITS interfaces and data exchange. Such standards have the following benefits and impacts:

- **Expanded markets and lower costs.** Open interface standards may result in an expanded market for ITS products and services, with resulting price competition and lower final costs to the end user. Such an expanded market may in turn result in network externalities, where simply having more users may mean additional cost reductions or increased benefits for users (e.g. route guidance, dynamic ridesharing, or regional traffic management).

- **Compatibility.** Open interface standards also provides many technical benefits to the end user, including: portability, inter-operability, and easier data exchange between ITS applications.

- **Technology innovation.** ITS standards may impede the long-term adoption of innovative technologies surrounding a given standard. For example, wide-area wireless communication standards for ITS could be "locked in" to a certain technology before more useful or cost-effective technologies have a chance. Thus, a standard may lead to an ITS industry settling on inferior technology. However, a standard may also serve to promote rapid technology development and innovation for specific components. The net impact on technology development is not easily quantified.

- **Vendor interests.** The long-term benefits of standards to ITS product and service vendors may be very favorable. In markets such as for ITS, industry consensus standards can result in the development or expansion of the market altogether. While there may be some natural resistance to standards from some large companies with high investment in proprietary systems, there may be considerable benefits to increasing market competition among both users and vendors.

A second major benefit of the architecture is the extent to which the architecture leverages integration of transportation functions, information flows and technologies. This integration is possible because the national architecture results from a comprehensive analysis of ITS user services. That is, the architecture suggests desired interfaces to achieve a comprehensive range of ITS services. The benefits of this integration include:

- **Data/information sharing for system management and planning.** Through the many data flows and interfaces, the architecture identifies how organizations can share data and information. In many cases, such information sharing is necessary to provide particular user services. Perhaps more importantly, these data and information can be used for better transportation system management and operations. Hence, the sharing of transportation performance data through the architecture may lead to more effective use of scarce transportation resources and better system-wide planning (e.g. with traffic and transit management, multi-modal coordination, etc.).

- **Common functions and functional integration.** There are many functions within the architecture that either 1) are common to several market packages or 2) may be integrated with functions in other market packages to provide higher benefits. By sharing certain functions between market packages, cost savings and operational efficiencies may be realized by the end users of these packages. In addition, integrating particular market packages allows higher benefits to be achieved. For example, route guidance can be connected with regional traffic control. This integration allows an ISP to provide better routing advice, given that they know the arterial and freeway signal plans. In turn, if the traffic managers know how vehicles will be routed, they can better time their traffic signals to accommodate this traffic.

- **Common technology.** Data flows and functions specified in the architecture may be combined, in a specific system design, to leverage common communications and other technology. Dedicated short-range communications devices can be used both for roadside toll collection, CVO vehicle check/clearance, and vehicle probe surveillance data. A single credit or debit card technology could be used for transit fare payment, toll and parking charges, or even non-ITS purposes. Software and hardware for map databases, as well as for position referencing systems (e.g. GPS), are needed for a broad range of ITS market packages, and can leverage system standards in these areas.

In addition, there are several features of the national architecture that will enhance the level of benefits of the 29 ITS user services outlined by the FHWA. The architecture includes a number of features that will facilitate the development and growth of ITS, and in the process will support the realization of benefits from market package deployment. In this section, we describe those features of the architecture that may assist in the development of a market for ITS products and services, including:

- Sensitivity to larger transportation planning and policy objectives
- System flexibility and openness
- System modularity
- Support for multiple levels of functionality and technical sophistication
- Leverage of existing infrastructure and communications systems
- Balanced approach to interface specification
- Deployment within existing institutional arrangements
- Effective allocation of costs and benefits
- Availability of early planning information for future deployments

Each of these points is addressed in the following paragraphs.

<u>Sensitivity to Larger Transportation Planning and Policy Objectives</u>

Our current understanding of the role of a national ITS system architecture is that it is intended to be a tool that enables actions to reach regional, state, and federal transportation objectives. This argument follows from our understanding of the role of ITS in enhancing the nation’s transportation system and encouraging economic productivity and new ITS-related industries. This orientation was mentioned in the objectives of the benefits analysis, in Section 3.1, and was described in Figure 3.1-1.

The National Architecture supports a regional, state, and federal deployment of the architecture in a manner that is consistent with these larger transportation, economic, social, and political goals. The key to the architecture in this regard is its flexibility in deployment. We expect that public agencies may have different transportation policies and goals, and thus may have different interests in the types of problems they wish to address and objectives in seeking solutions to those problems. To this end, the architecture supports market packages that may be used as “ITS tools” to help solve these transportation problems. Ultimately, however, the deployment of particular market packages within the architecture depends upon how local, regional, state, and federal planners and policy-makers choose to deploy the architecture. This is a key point to keep in mind when evaluating the potential benefits of any architecture.

System Flexibility and Openness

The National Architecture emphasizes flexibility and openness. For a given architecture deployment, all components of the architecture are non-proprietary. This means that the number of potential firms that may enter the ITS market is not limited by the definition of the architecture. Thus, any number of firms may enter the market for devices, for communications systems, for hardware and software, etc. Second, the architecture is also flexible, which in this context means that we expect devices to be compatible to an interface, but what goes on behind the interface is not touched. A firm may have a special product or service it is willing to offer, and the only restriction placed on that firm is that it has the appropriate interfaces to other subsystems in the architecture. This specification of interfaces, but not the internal workings of each architecture subsystem, means that there is ample opportunity for innovation in product and service design. All of these factors suggest that a market for ITS products and services may develop with only minimal specification of functions and interfaces.

System Modularity

The system architecture is modular and expandable. The equipment packages and market packages may be implemented in a modular and expandable fashion. The specification of key interfaces guarantees that any product or service that is developed is 100% compatible with other systems and technologies in the architecture. Again, the architecture does not specify technologies or the detailed design of functions; rather, it simply assures that any technologies that are so developed are compatible with other parts of the architecture. To a device or service supplier, this ensures that their end product will work with other systems, and encourages their participation in the development and deployment of ITS services.

Support for Multiple Levels of Functionality and Technical Sophistication

In a similar light, the National Architecture supports multiple levels of functionality and multiple levels of technical sophistication. In terms of functionality, a firm interested in providing a device or service has several options for the level of functionality of that device or service. For example, in the realm of traveler information services, a firm may market a simple paging device that allows the user to access broadcast traffic information. Another firm could market a device that not only receives that information, but allows the user to query for particular pieces of information, allowing greater user interaction. Both levels of functionality are covered in the architecture. Thus, a firm entering the ITS industry has a wide variety of possible ways to enter the market, depending on the chosen level of function and technical sophistication. These features further support the development of a wide variety of products and services for a growing ITS market.

Leverage of Existing Infrastructure and Communications Systems

The Joint Team’s architecture, as described in the *Physical Architecture* document and evaluated in Section 2.1.5, leverages existing infrastructure and communications systems. From the perspective of the existing hardware and software, the architecture merely requires that these existing systems have appropriate external interfaces in order to function within the architecture. In this sense, the compatibility of the architecture with existing infrastructure is high, and there is little or no significant investment required to make existing hardware and software compatible with the architecture. In addition, the architecture leverages existing communications systems where possible. For wide-area communications services, this means that no new ITS-dedicated communications system is required; the architecture leverages existing cell-based communications technologies to provide wide area coverage. Wide-area wireline services will also leverage existing fiber and other wireline networks to handle communications needs. For short-range mobile communications (i.e., vehicle to roadside and vehicle to vehicle), the architecture supports ongoing development and specification of these communications systems.

Balanced Approach to Interface Specification

The architecture will specify interfaces between subsystems; indeed, this specification of interfaces is one of the main purposes of a physical architecture. The level of detail to which these interfaces are specified is also an important piece of the National Architecture. If an interface is over-specified, it may restrict the development of the market for products and services designed to that interface. On the other hand, if an interface is not specified, then particular hardware and software may not be compatible with other systems. The specification of interfaces is described in greater detail in the *Standards Development Plan*, the *Standards Requirements*, and the *Implementation Strategy* document submitted separately.

Deployment Within Existing Institutional Arrangements

Because of the scope of potential problems in the institutional area, institutional issues are seen as critical both to the public's acceptance of ITS and to the technical performance of the architecture. Within the architecture, there is considerable flexibility in working with institutions. First, the architecture does not require new institutional arrangements in its implementation. The architecture itself is modular both in function and in geography, allowing agencies to implement ITS market packages as they see these packages fitting in with their transportation policies and goals. Moreover, as these packages are implemented, the interface with other institutions is entirely cooperative; that is, the architecture supports cooperative (but not mandatory) information sharing between institutions. In this way, institutions do not need to surrender any of their operating authority in connecting into the architecture, nor do they necessarily assume new responsibilities or control through their participation. In this way, the deployment of the architecture is sensitive to local and regional institutions regarding cooperation and responsibilities for information management.

Effective Allocation of Costs and Benefits

In Section 6.2, we describe the potential allocation of benefits of each of the market packages in the National Architecture across individuals, public and private organizations, and society as a whole. The accrual of benefits identified in Table 5.2-8 has some clear implications for the architecture. First, in many cases it is relatively easy to identify direct beneficiaries who may bear the costs of these market packages directly, and can be expected to pay for services on a pay-for-use basis. This is especially true for the ATIS and AVSS market bundles, in which the benefits accrue to those who have the requisite equipment for each market package. Thus, one might expect that those individuals who receive the benefits will also be the ones who pay for them, through their purchase and operation of this equipment. A similar argument could also be made for the CVO and APTS market bundles. In these cases, the most obvious direct beneficiary is the fleet manager and transit agency, respectively. These organizations may also be expected to purchase these market packages directly, and then pass these costs on to their customers (as "indirect" beneficiaries). The equity of this allocation of costs to transit passengers by a (likely public sector) transit agency may be questionable, however.

For the ATMS and EM market bundles, benefits accrue to all roadway travelers and in many cases to society at large. Benefits also accrue to HOV and transit users, who will receive benefits under a number of the ATMS market packages, but whose choice of mode also enhances broader societal goals of increasing mobility and enhancing system-wide traffic flow. There is an open question about how such market bundles that provide social benefits (ATMS, APTS, and EM) may recover costs in an equitable manner. However, the architecture does support pricing mechanisms, through the demand management market package, that may be used to allocate costs equitably among system users as they pay for their system use (e.g., through electronic payment capabilities for tolls, transit fares, parking, etc.).

6.2.2 Benefits from the ITS Market Packages

Different public agencies will have different objectives for ITS deployments due to disparities in the characteristics and constituents of locales across the nation. The architecture includes market packages that enable a range of public policies and achieve significantly different benefits. A fundamental step in evaluating the systems architecture and its deployment is to identify and emphasize those market packages that are most likely to solve the problems at hand.

From the analysis presented in Chapter 5.2, the Joint Team has developed qualitative estimates of the benefits that can be expected for each of the market packages. These projected benefits can be aligned with specific needs of a deploying agency to select the right market packages for deployment. Repeating a table from that section, Table 6.2.1 associates the market packages with the ITS goals identified in the *Mission Definition* document based on this analysis. As might be expected, different goals are supported by different groups of market packages. Also evident is that several of the market packages assist in attainment of multiple goals; such market packages are likely early winners that should be promoted through early deployments. The following narrative summarizes the market packages which should be targeted to address each of the goals.

- Increase Transportation System Efficiency: This goal is most applicable to outlying urban areas and suburbs where congestion is a significant problem and road capacity increases are the desired solution (e.g., alternative modes are not present or do not provide a viable alternative to private vehicles). The indicated market packages, which improve the effective capacity of existing transportation facilities, provide an attractive alternative to new construction. Each of the ATMS, ATIS, and EM market packages identified as the strongest contributors to this goal (**) are projected to achieve significant reductions in vehicle delays, comparable reductions in the number of stops, and only small increases in VMT. The effective capacity improvements due to the identified AVSS market packages are expected to be very significant.

- Increase Mobility: This goal applies to congested areas which wish to influence both demand and capacity to improve mobility for individuals. Those market packages identified as strongly correlated with this goal provide service enhancements and better information regarding these improved services. Improved information in a pre-trip environment has the greatest potential to provide individual travel time and cost savings.

- Reduce Energy Consumption and Environmental Cost: Realizing this goal might have particular emphasis for areas in non-attainment with federal air quality standards. Strongly correlated market packages smooth traffic flow resulting in higher average network speeds and fewer stops which suggests reductions in fuel usage and emissions. The Emissions Monitoring and Environmental Hazards Sensing market package allow pro-active response to any induced demand which might negate network performance improvements.   Public transit packages are also included to optimize transit performance which may induce (unquantified) demand shifts to favor more environmentally friendly travel modes.

- Improve Safety: This goal has universal importance but is especially significant in rural areas which experience a disproportionate number of serious accidents. Each of the strongly correlated market packages have clear safety benefits. The safety benefits for the weakly correlated AVSS market packages are potentially substantial but uncertain at this time due to uncertainties in the evolution of these technologies.

- Increase Economic Productivity: This is also a universal goal that may be particularly attractive to the individuals, public agencies, and private agencies most likely to benefit. Achieving this goal through the ITS market packages involves providing individuals as well as public and private agencies with a more efficient and cost-effective means of doing business. Selected market packages automate financial transactions, enhance management of commercial, transit, and emergency fleets, and facilitate goods movement.

- Enhance the ITS Market: This goal directly affects the characteristics of the physical architecture and its deployment; however, it does not closely correlate with individual market packages. Each of the market packages, since they embody new goods and services, are likely to encourage industry assuming the markets are viable. The success of such industry depends on an open architecture and a non-restrictive deployment strategy to encourage participation and innovation. Emphasis in this case is placed on the size of the market that may be anticipated; for example, one might expect markets for market packages for the private automobile might be much larger than those for transit agencies.

In addition, Table 6.2-2 describes the allocation of benefits by market package for both direct and indirect beneficiaries. To the greatest extent, this distribution further supports the objective of the architecture of providing benefits to those who pay (either directly or indirectly) for the services provided in these market packages.

Within the ATIS market bundle, we observe that the direct beneficiaries are those who have purchased or who have access to ATIS equipment. However, unequipped drivers may also experience benefits, resulting from the changes in travel patterns when equipped drivers change departure time, mode or route in response to information.

The general pattern, however, suggests that those who receive the direct benefits of these services will be those who make the decision to purchase this ATIS equipment.

For the ATMS market bundle, the benefits fall among a broad range of the traveling public. All roadway travelers receive benefits of enhanced traffic and incident management. Because they are designed to support existing traffic management functions, the traffic management market packages provide direct benefits to traffic managers. Yet, the information thus gained will be used to benefit all travelers, and especially those who may use such information in ATIS services. Other services such as toll and parking fee payment benefits those who are equipped; the likely low cost of equipment leads us to believe that the number of equipped travelers will be considerably larger than those for the more expensive ATIS devices.

The APTS market packages, as might be expected, yield direct or indirect benefits for transit users and the transit management center. In all cases, however, the primary beneficiary includes the transit agency itself. This may indicate that transit users will not perceive direct benefits from many of these market packages, even though the transit agency is enhancing its own service delivery.

Commercial vehicle operators, in the form of fleet managers and drivers, receive significant benefits from the market packages in the CVO market bundle. Fleet managers are the direct beneficiaries of all market packages, as their operations may be streamlined through automation of many management and administrative tasks. Likewise, fleet drivers may also receive indirect benefits from all seven market packages, as their driving is subject to less delay at ports of entry and inspection facilities and as they receive additional support from fleet managers through routing and dispatch. Shippers also receive indirect benefits through more timely arrival of shipments and improved tracking and safety of goods that are shipped. Government regulators also receive direct benefits, as their administrative work is reduced through electronic filing of credentials, safety inspection, and weigh-in-motion capabilities at roadside facilities.

The emergency management market packages provide direct benefits to the emergency management center, through automating emergency response and facilitating vehicle operations. More directly, the emergency response market package has direct benefits for travelers involved in incidents, and also results in indirect benefits to society at large as there can be faster response to emergencies. Finally, and perhaps most obviously, the safety benefits of the AVSS market packages will accrue to those whose vehicles are equipped.

Table 6.2-1: Benefits of Market Packages for Achieving ITS System Goals

		ITS System Goals					
	Market Packages	Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
APTS	Transit Vehicle Tracking	*	**	*		*	*
APTS	Fixed-Route Operations	*	**	*		*	*
APTS	Demand-Responsive Operations	*	**	*		*	*
APTS	Passenger and Fare Management					**	*
APTS	Transit Security				**		*
APTS	Transit Maintenance					*	*
APTS	Multi-modal Coordination	*	*			*	
ATIS	Broadcast Traveler Info	*	**	*			***
ATIS	Interactive Traveler Info	**	***	*			***
ATIS	Autonomous Route Guidance	**	***				***
ATIS	Dynamic Route Guidance	**	***	*	*		***
ATIS	ISP-Based Route Guidance	**	***	*	*		***
ATIS	Integrated Transportation Mgmt / Route Guidance	***	***	**	*		**
ATIS	Yellow Pages and Reservation		*				**
ATIS	Dynamic Ridesharing	**	*	*			*
ATIS	In Vehicle Signing		*		*		***
ATMS	Network Surveillance	*	*	*			*
ATMS	Probe Surveillance	*	*	*			**
ATMS	Surface Street Control	**	***	**	**		*
ATMS	Freeway Control	**	***	**	*		*
ATMS	Regional Traffic Control	***	***	***	**		*
ATMS	HOV and Reversible Lane Management	*	**	*			*
ATMS	Incident Management System	**	**	***	**		*
ATMS	Traffic Information Dissemination	**	*	*			*
ATMS	Traffic Network Performance Evaluation	**	**				*
ATMS	Dynamic Toll / Parking Fee Management					**	*
ATMS	Emissions and Environ. Hazards Sensing			***			**
ATMS	Virtual TMC and Smart Probe Data	*	*	*		*	*
CVO	Fleet Administration		***			***	**
CVO	Freight Administration		***			***	**
CVO	Electronic Clearance	**	***			***	**
CVO	CV Administrative Processes					**	*
CVO	International Border Electronic Clearance	**	***			***	**
CVO	Weigh-In-Motion	**	***			***	**
CVO	CVO Fleet Maintenance	*			**	**	*
CVO	HAZMAT Management	*			**	**	*
CVO	Roadside CVO Safety	*	**		**	**	**
CVO	On-board CVO Safety				***	**	**

Key: * = low benefit, ** = moderate benefit, *** = high benefit

Table 6.2-1: Benefits of Market Packages for Achieving ITS System Goals (Continued)

	Market Packages	ITS System Goals: Increase Transportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improve Safety	Increase Economic Productivity	Create an Environment for an ITS Market
AVSS	Vehicle Safety Monitoring				***		***
	Driver Safety Monitoring				***		***
	Longitudinal Safety Warning				***		***
	Lateral Safety Warning				***		***
	Intersection Safety Warning				***		***
	Pre-Crash Restraint Deployment				***		***
	Driver Visibility Improvement				***		***
	Advanced Vehicle Longitudinal Control	**	*		***		***
	Advanced Vehicle Lateral Control	**	*		***		***
	Intersection Collision Avoidance				***		***
	Automated Highway System	***	***		***		***
EM	Emergency Response	*		*	***	**	*
	Emergency Routing	*		*	***	**	*
	Mayday Support				***	*	**
ITS	ITS Planning	**	**	**	**	**	***

Key: * = low benefit, ** = moderate benefit, *** = high benefit

Table 6.2-2: Benefits Allocation of ITS Market Packages

MARKET PACKAGE	SOCIETY	TRAFFIC MANAGEMENT CENTER	TRANSIT MANAGEMENT CENTER	EMERGENCY MANAGEMENT CENTER	FLEET MANAGERS	FLEET DRIVERS	EQUIPPED TRAVELERS	UNEQUIPPED TRAVELERS	TRANSIT & HOV USERS
Broadcast-based ATIS							Direct	Indirect	
Interactive Traveler Information							Direct	Indirect	
Autonomous Route Guidance							Direct	Indirect	
Dynamic Route Guidance							Direct	Indirect	
ISP Based Route Guidance							Direct	Indirect	
Integrated Transportation Management/Route Guidance							Direct	Indirect	
Yellow Pages and Reservation							Direct	Indirect	
Dynamic Ridesharing							Direct	Indirect	Direct
In Vehicle Signing							Direct		
Network Surveillance	Indirect	Direct					Indirect	Indirect	Indirect
Probe Surveillance	Indirect	Direct					Indirect	Indirect	Indirect
Surface Street Control		Direct					Indirect	Indirect	Indirect
Freeway Control		Direct					Indirect	Indirect	Direct
HOV and Reversible Lane Management		Direct					Direct	Direct	Direct
Traffic Information Dissemination	Indirect	Direct					Direct	Direct	Direct
Regional Traffic Control	Indirect	Direct					Indirect	Indirect	Indirect
Incident Management System	Indirect	Direct	Direct				Direct	Indirect	
Traffic Network Performance Evaluation	Indirect	Direct					Indirect	Indirect	Indirect
Dynamic Toll/Parking Fee Management	Indirect	Direct					Direct	Indirect	
Emissions and Environmental Hazards Sensing	Indirect	Indirect					Direct	Indirect	
Virtual TMC and Smart Probe Data	Indirect	Direct					Direct	Indirect	

Table 6.2-2: Benefits Allocation of ITS Market Packages (Continued)

MARKET PACKAGE	SOCIETY	TRAFFIC MANAGEMENT CENTER	TRANSIT MANAGEMENT CENTER	EMERGENCY MANAGEMENT CENTER	FLEET MANAGERS	FLEET DRIVERS	EQUIPPED TRAVELERS	UNEQUIPPED TRAVELERS	TRANSIT & HOV USERS
Transit Vehicle Tracking			Direct						Indirect
Fixed-Route Operations			Direct						Direct
Demand Responsive Transit Operations			Direct						Direct
Passenger & Fare Mgmt			Direct						Direct
Transit Security			Direct	Indirect					Direct
Transit Maintenance			Direct						Indirect
Multi-Modal Coordination			Direct						Direct
Fleet Administration					Direct	Indirect			
Freight Administration					Direct	Indirect			
Electronic Clearance					Direct	Indirect			
CV Adminstrative Processes					Direct	Indirect			
International Border Electronic Clearance					Direct	Indirect			
Weigh-In Motion					Direct	Indirect			
Roadside CVO Safety					Direct	Direct			
On-Board CVO Safety			Indirect		Direct	Direct			
CVO Fleet Maintenance					Direct				
HAZMAT Management		Direct			Direct				
Emergency Response	Indirect			Direct			Direct	Direct	
Mayday Support				Direct					
Emergency Routing	Indirect			Direct			Indirect	Indirect	
Vehicle Safety Monitoring							Direct		
Driver Safety Monitoring							Direct		
Longitude. Safety Warning							Direct		
Lateral Safety Warning							Direct		
Intersection Safety Warning							Direct		
Pre-Crash Restraint							Direct		
Driver Visibility Improvemt.							Direct		
Vehicle Longitudinal Control							Direct		
Vehicle Lateral Control							Direct		
Intersection Collision Avoidance							Direct		
Automated Highway System							Direct		
ITS Planning	Indirect								

Final Performance and Benefits Summary

Appendix A
Benefits Flow Diagrams

The approach of the Joint Team is to define the benefits flow diagrams in terms of the immediate connection of each of the Team's proposed market packages to transportation system metrics. The transportation metrics that we suppose are **directly** affected by each market package are identified first. In order to present a consistent message on the Joint Team's approach of market packages, the logical connections of market packages to benefits metrics are shown in Section A.1. Section A.2 presents the logic flow diagrams that connect these immediate system metrics to the ITS system goals. In each of the diagrams in Section A.1, a figure reference box is given that connects the transportation system metrics to the discussion of ITS goals in Section A.2.

A.1 Connection of Market Packages to Transportation System Metrics

Each of the Joint Team's market packages has some immediate impact upon driver behavior, costs, accidents, or the like which has immediate impact upon the transportation system. These benefits (or costs, depending on the relative impact) are a direct result of the services provided by that market package and its effect on travelers in the transportation system. The following description outlines what effect these market packages have on the transportation system directly, using some quantitative transportation system metrics. In the discussion below, the market packages are grouped into bundles as suggested in Table 1.1-1.

A.1.1 Advanced Traveler Information Systems (ATIS) Market Bundle

The advanced traveler information system (ATIS) market bundle includes those market packages that directly affect an individual traveler. The first market package, broadcast traveler information, is intended to be a low-end service for driver information about current traffic conditions. Figure A.1-1 suggests that information about travel characteristics on alternate routes and modes provided to the traveler in this manner, both before and during their trip, will result in reductions in the individual's travel time and the day-to-day travel time variability. These effects will result from the traveler making better decisions about possible modes and routes for their trip. One may also expect that this information will cause travelers to avoid bottlenecks and congestion, with resulting reductions in delay, avoidance of queues, and less exposure to accidents and other travel-related incidents.

The benefits metrics shown above are also applicable for more interactive traveler information market packages. Basic interactive traveler information for drivers and travelers, as might be expected in a pre-trip situation, is depicted in Figure A.1-2. Before travelers begin their trip, they may receive information on their travel options, including the levels of congestion on various routes, optimal route advice, and information about alternate modes. This pre-trip information intuitively may lead to better route and mode choices by travelers, as travelers avoid bottlenecks in the transportation network. This will result in reduced queue lengths, reduced congestion-related delay time for each trip, and a direct reduction in the variability of travel times in the network.

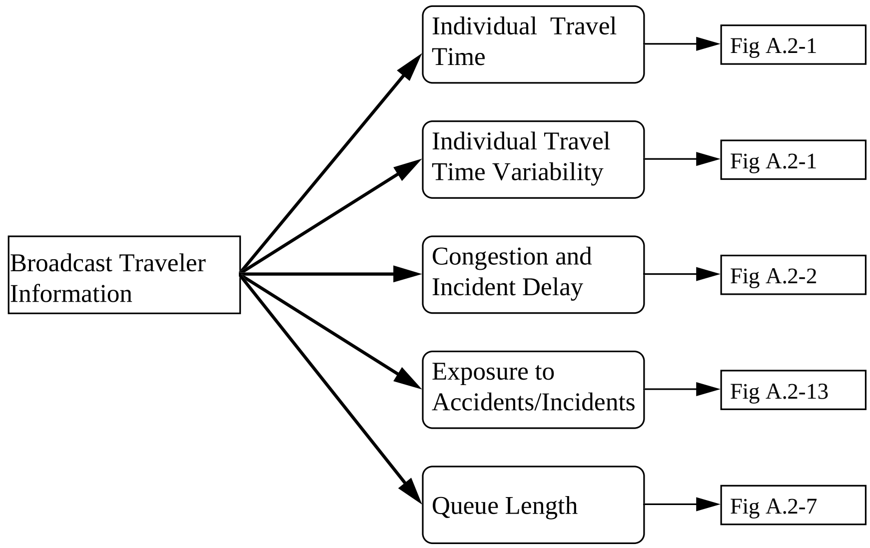

Figure A.1-1: Metrics from Broadcast Traveler Information

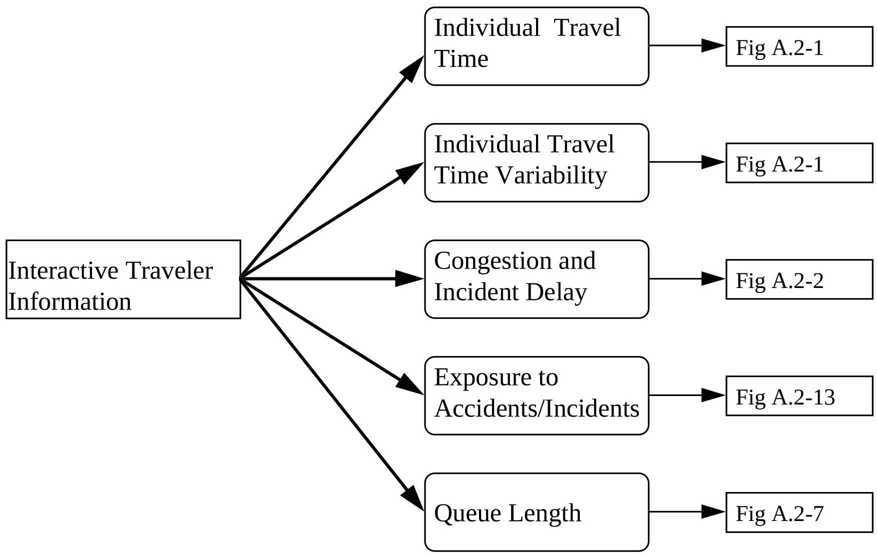

Figure A.1-2: Metrics from Interactive Traveler Information

Logical impacts of route guidance and planning are shown in Figures A.1-3 through A.1-5, for autonomous route guidance, dynamic route guidance, and ISP-based route guidance, respectively. infrastructure-based route selection). As with the previous market packages, route planning can help travelers to avoid congestion parts of the street network and guide them directly to parking at their destination. Again, these types of user services will directly reduce individual travel times, travel time variability, and queue lengths as travelers avoid congested sections in the travel network.

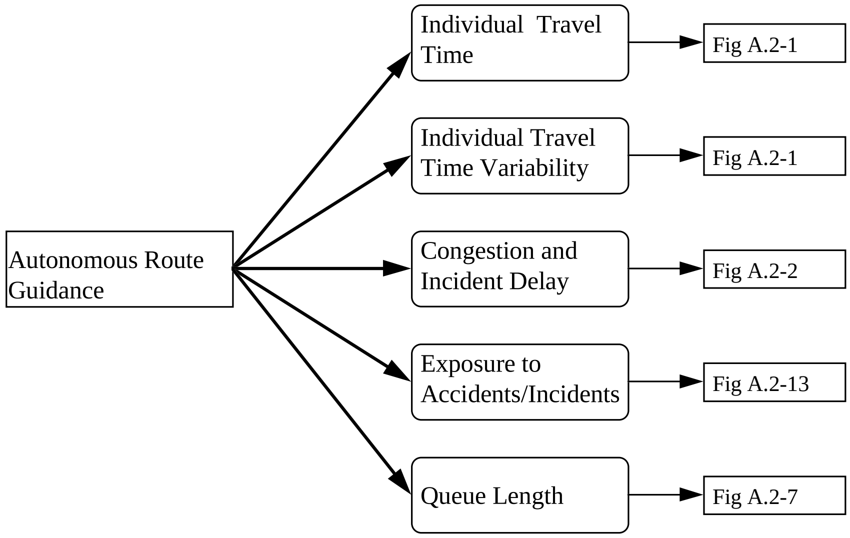

Figure A.1-3: Metrics from Autonomous Route Guidance

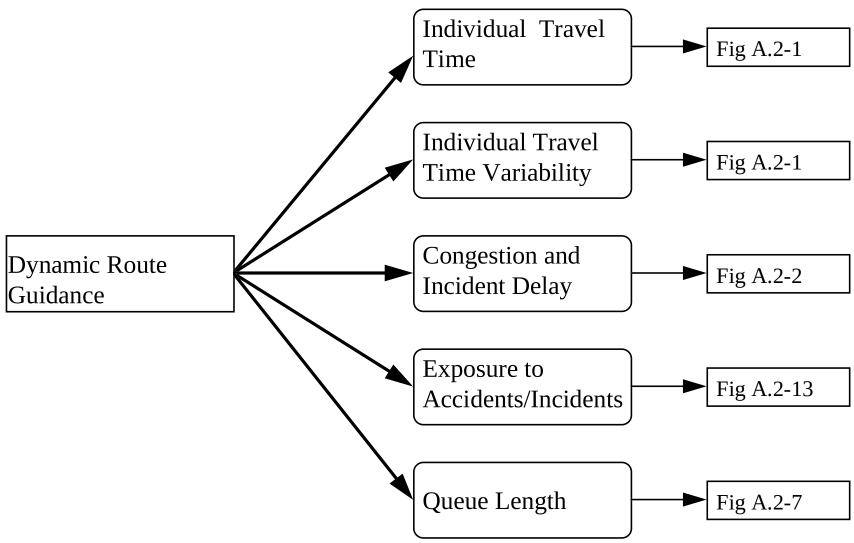

Figure A.1-4: Metrics from Dynamic Route Guidance

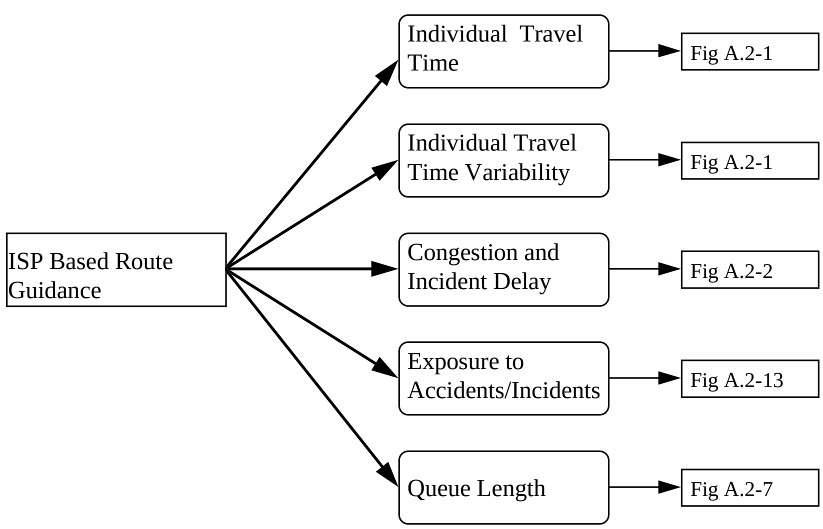

Figure A.1-5: Metrics from ISP-Based Route Guidance

At a relatively high end state, there may be functional coordination between route selection in ATIS and the traffic control actions taken by traffic managers. The benefits of such a system are numerous: there may be high synergy in directing traffic to streets and roadways where traffic control is modified to accept that traffic. Benefits metrics in this case, as shown in Figure A.1-6, result from a merger of those of interactive traveler information and regional traffic control. Benefits of such synergy may be more or less than additive from the two strategies implemented separately.

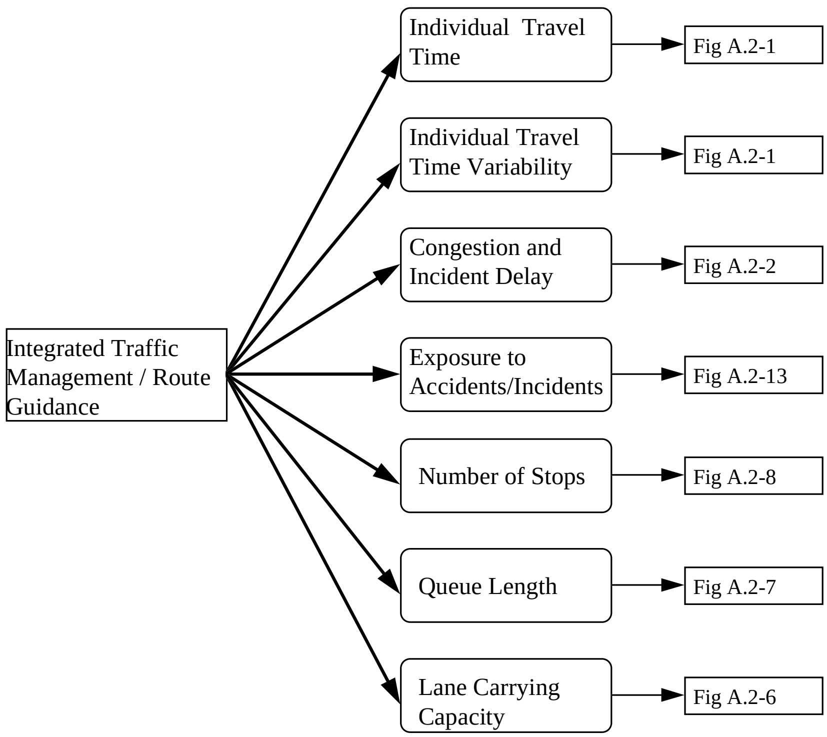

Figure A.1-6: Metrics from Integrated Transportation Management / Route Guidance

For travelers who are unfamiliar with the services in a geographic area, benefits of on-line yellow pages and reservations services are indicated in Figure A.1-7. For such individuals, a yellow pages service might help them to locate a particular destination faster and reduce the mileage and time spent looking for an unfamiliar location (i.e. without getting lost). Thus, reductions in travel times and time and effort spent searching for appropriate destinations are expected.

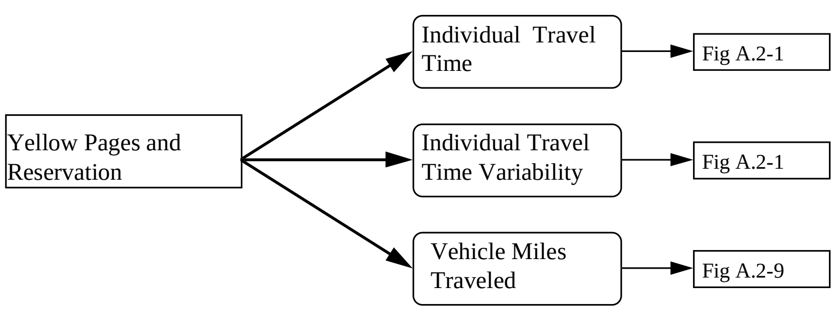

Figure A.1-7: Metrics from Yellow Pages and Reservation

Other ATIS services may provide a dynamic ridesharing capability, to provide a basic level of mobility for those willing to join a carpool or vanpool. Benefits of such a package are indicated in Figure A.1-8. As this market package would be implemented, travel time savings and reductions in travel time variability are expected (e.g. by using an HOV lane). The availability of the service itself may have the effect of increasing the level of information and resulting utility of high-occupancy vehicle travel. Finally, travel costs for the mobility-impaired may also be reduced through this service.

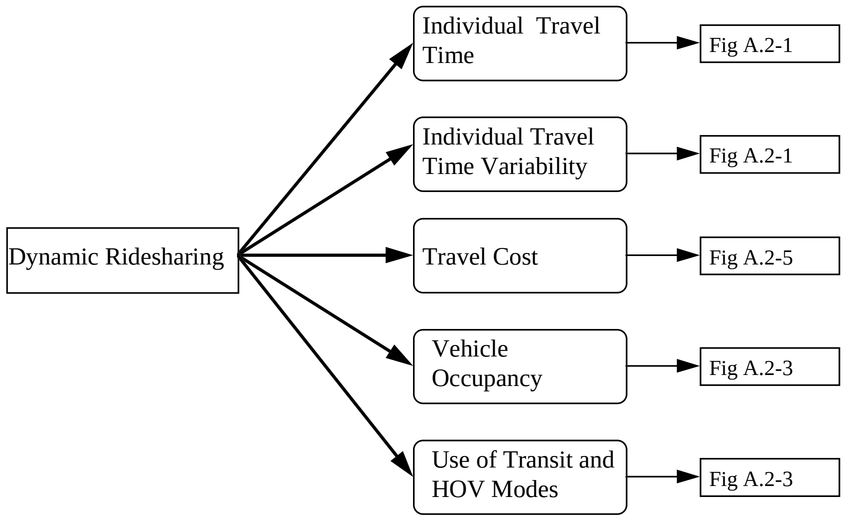

Figure A.1-8: Metrics from Dynamic Ridesharing

Finally, the in-vehicle signing market package allows communication of local traffic information to the vehicle. The logical dependencies shown in Figure A.1-9 show that this information may have two direct consequences. First, this information may lead to a reduction in individual time and miles, as drivers receive information to make better driving decisions. Second, a reduction in the number of accidents may also result, as the driver is receiving local traffic conditions and weather-related advisories. Both of these types of information may result in safer driving, based on the improved decision-making opportunities for the driver.

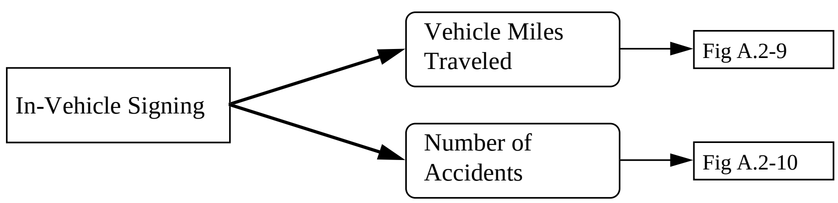

Figure A.1-9: Metrics from In-Vehicle Signing

A.1.2 Advanced Traffic Management Systems (ATMS) Market Bundle

The advanced traffic management system (ATMS) market bundle includes those packages to facilitate the function of the traffic system as a whole. The first several market packages provide a basic level of functionality in information collection and system management. The first two packages constitute different means of traffic network surveillance; as such, they provide a basic level of support for other ATMS-related market packages, such as signal control, incident detection, and incident response. Such data may also be used by traveler information service providers to give up-to-date traffic information to road users. Finally, such surveillance will have a direct impact on infrastructure costs for the traffic management agency. Figure A.1-10 demonstrates this logical dependency for the (stationary) network surveillance market package, while Figure A.1-10 describes this for probe vehicle surveillance.

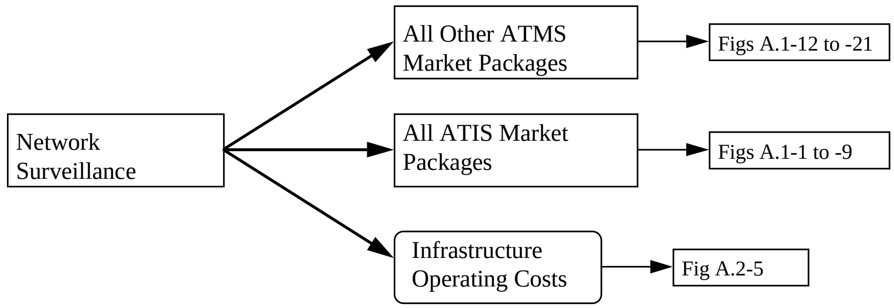

Figure A.1-10: Metrics from Network Surveillance

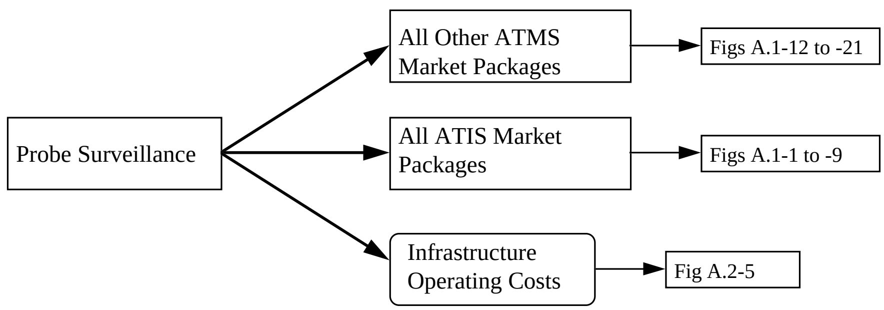

Figure A.1-11: Metrics from Probe Vehicle Surveillance

Perhaps in conjunction with these surveillance capabilities, an arterial and surface street control market package can be implemented. Benefits of resulting levels of signal coordination and other basic traffic management techniques are indicated in Figure A.1-12. Typically, by coordinating traffic signals and other traffic control activities, vehicles will spend less time in queue at traffic signals, with associated delays. Such signal control also increases intersection throughput, shown here in the metric of lane-carrying capacity.

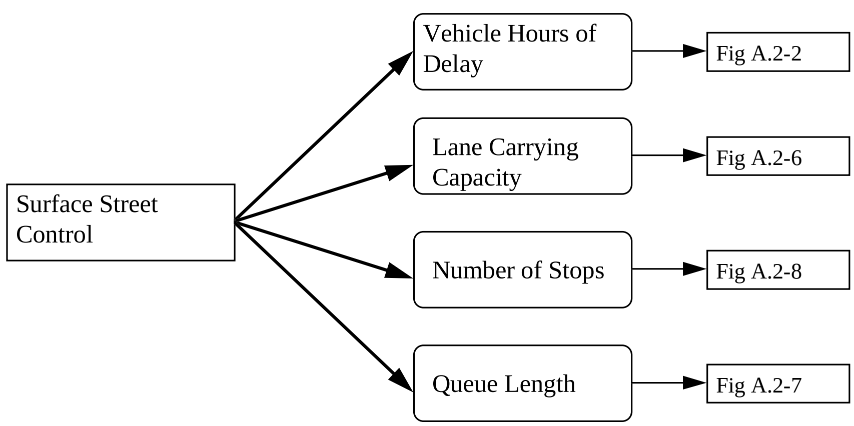

Figure A.1-12: Metrics from Surface Street Control

The benefits of freeway control systems, such as ramp meters and other techniques to enhance main-line traffic flows, are common of most traffic control systems. These benefits, shown in Figure A.1-13, include smoothing of main-line traffic on freeways to reduce queueing and stops and associated delays for the traveler. Greater lane capacities on the freeway may result from such smoother flows. However, capacities of freeway on- and off-ramps may be diminished, however, by the ramp metering.

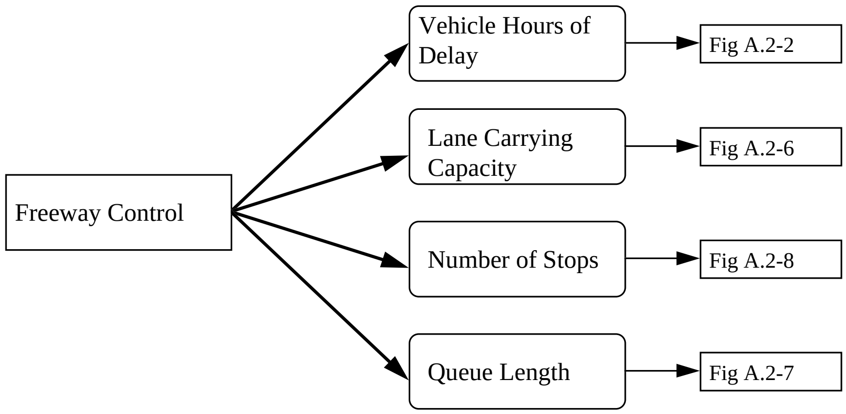

Figure A.1-13: Metrics from Freeway Control

As shown in Figure A.1-14, the HOV and reversible lane management package allows for priority treatment of HOV and transit vehicles for lane access control, bypassing stops at ramp meters and ensuring limited access to other HOV facilities. These dedicated facilities will improve HOV and transit travel times and also are expected to attract new HOV traffic. Traffic diverted to HOV facilities will result in shorter queue lengths and stops at ramps, as well as reduced delay in the normal traffic lanes. In addition, reversible lane facilities yield higher capacity for peak direction flows during peak traffic periods, thereby using existing road infrastructure more efficiently (i.e. improving lane carrying capacity). In addition, this increase in effective capacity will also serve to alleviate bottlenecks and associated congestion in the traffic network during peak hours.

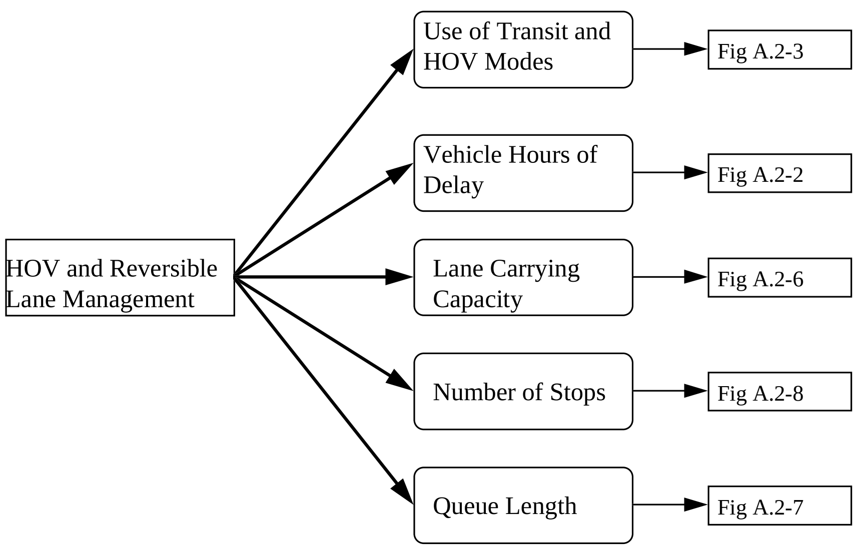

Figure A.1-14: Metrics from HOV and Reversible Lane Management

A basic level of traffic information dissemination is provided within the ATMS market packages in the architecture. By using highway advisory radio, changeable message signs, etc., traffic conditions can be quickly communicated to drivers. Similarly to many of the ATIS market packages, this service allows travelers to avoid congestion, reducing their travel times by avoiding congestion and incident-related delays. Such benefits are shown in Figure A.1-15.

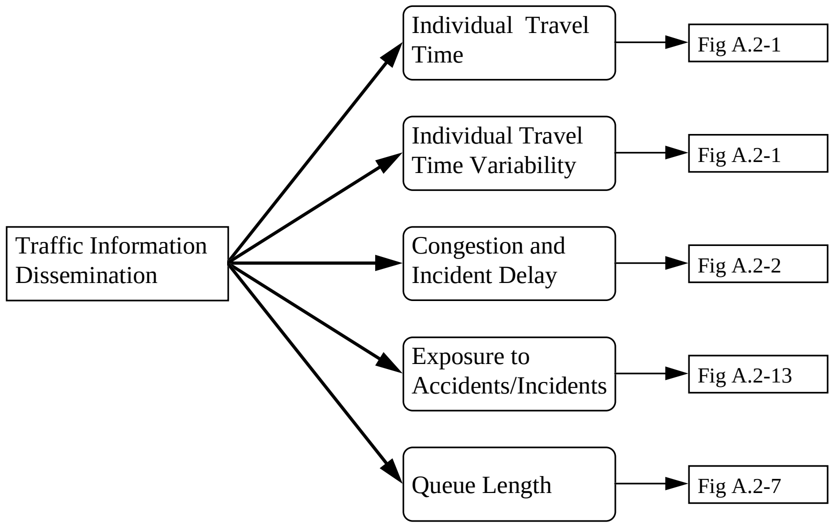

Figure A.1-15: Metrics from Traffic Information Dissemination

The market package incorporating more advanced integrated signal control for a wide geographic area (typically large metropolitan areas) is depicted in Figure A.1-16. Such coordinated region-wide traffic management supports a number of different user services, including traffic control, incident management, and some basic functions in travel demand management. This market package incorporates the same types of benefits as the more basic traffic monitoring and control packages mentioned previously, except at a higher level of functionality brought about through regional and inter-jurisdictional cooperation.

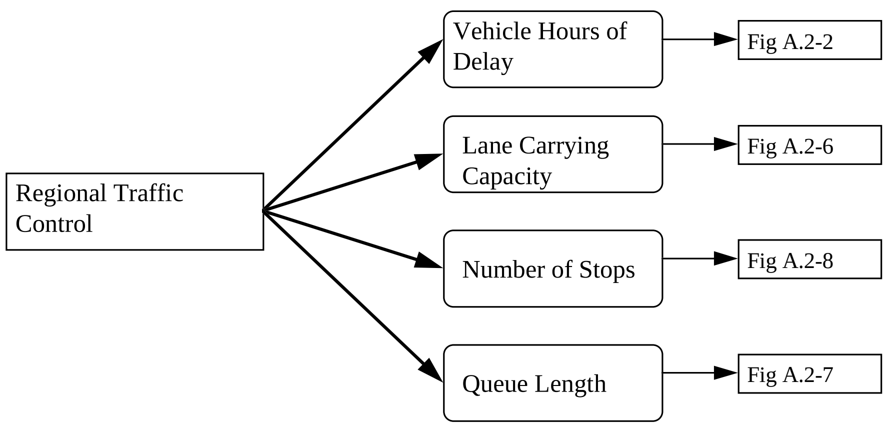

Figure A.1-16: Metrics from Regional Traffic Control

Specific benefits of incident detection and response capabilities are indicated in Figure A.1-17. The capabilities of these market packages include the ability to detect incidents and determine appropriate response actions. By coordinating the response plan among many organizations, further reductions in the time to respond to the incident may be achieved. Also, similar quick response will have the effect of clearing the incident, thereby reducing the size and possible occurrence of bottlenecks associated with the incident.

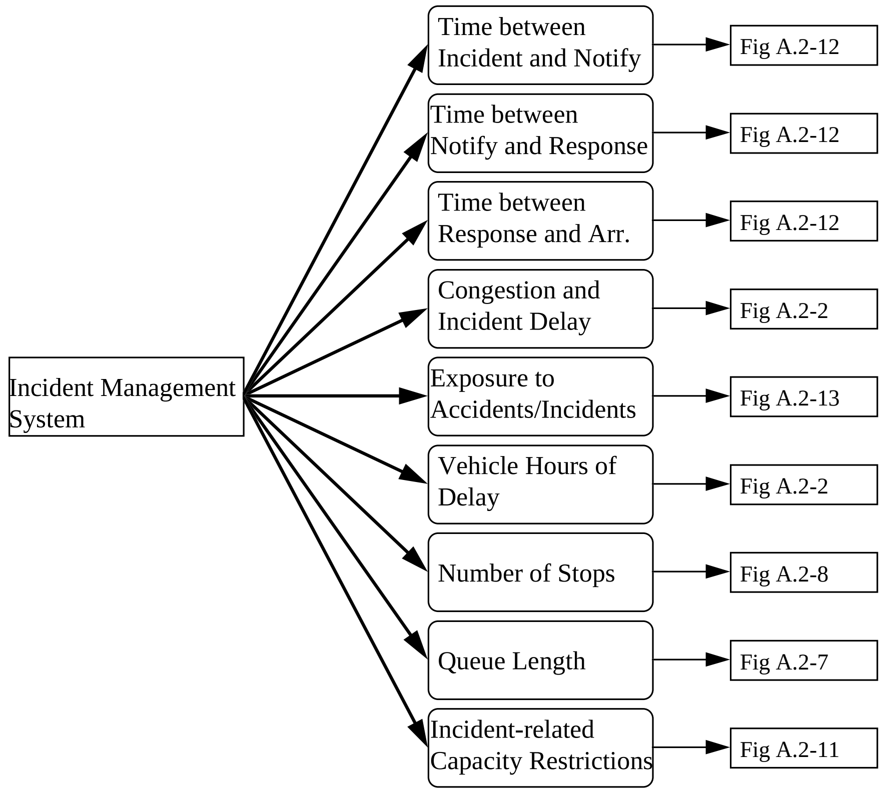

Figure A.1-17: Metrics from Incident Management System

The traffic network performance evaluation market package provides the capability of evaluating existing traffic conditions and estimating future traffic patterns. Rather than providing a direct product to travelers, the capability of this market package would serve to enhance the function of other market packages, as shown in Figure A.1-18. Most obviously, current or projected traffic conditions can be used to identify the day-to-day evolution of the traffic network. As a result, this market package may be adopted by those providing ATIS services. In addition, estimates of current and future travel patterns may also be used to enhance the traffic system control.

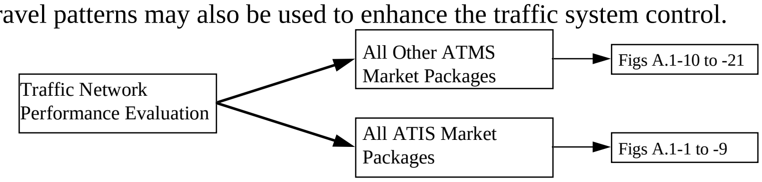

Figure A.1-18: Metrics from Traffic Network Performance Evaluation

The market package of dynamic toll and parking fee management allows automated, electronic collection of road user tolls and parking fees. The direct benefits of such a system are identified in Figure A.1-19. As with other pricing support functions in the architecture, automating the fee collection function may reduce administrative costs associated with financial transactions. In addition, because electronic payment services may directly affect pricing and payment options (as part of a travel demand management strategy), this service may have a direct effect on the costs of all travel modes, including auto, transit, and HOV travel. Finally, automated fee collection may result in a reduction (or even elimination) of queues at collection areas (e.g. at toll plazas).

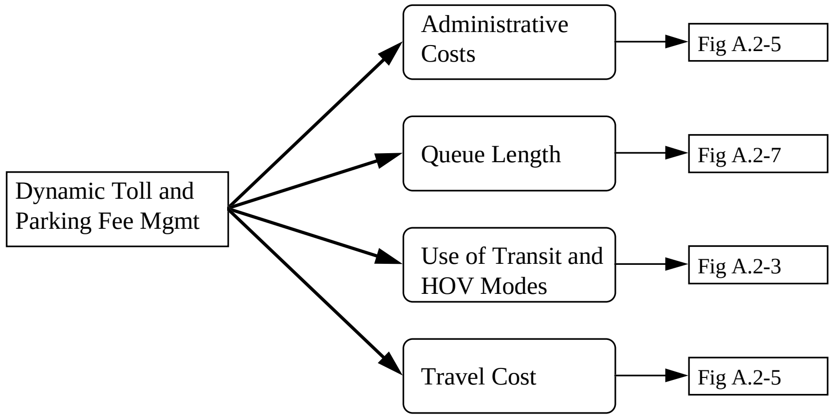

Figure A.1-19: Metrics from Dynamic Toll and Parking Fee Management

The emissions and environmental sensing market package allows policy actions to improve air quality and mitigate other environmental effects of transportation. An emissions monitoring function specifically allows monitoring of emissions both as a whole and for each vehicle. Using this data, any number of locally-appropriate traffic and vehicle control measures can be implemented to reduce emissions levels (shown in Figure A.1-20).

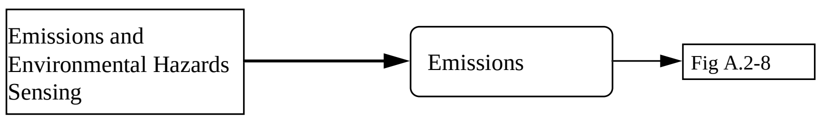

Figure A.1-20: Metrics from Emissions and Environmental Sensing

Finally, similar benefits of traffic management and incident response may also be achieved in more rural and inter-urban areas. However, more mobile traffic management activities may be done in these geographic areas, as a full permanent traffic management center may not be cost-effective. In such cases, a “virtual TMC” with smart probe vehicles may be sufficient to collect data on road conditions and make effective traffic management decisions. In such a case, a probe vehicle may serve to collect data, with information processing done at a local “virtual” center (e.g. a portable PC with a two-way radio connection). Figure A.1-21 indicates that such a market package may provide surveillance-related benefits to other ATMS and ATIS market packages. In addition, such capabilities may also result in faster incident detection from these intelligent probes.

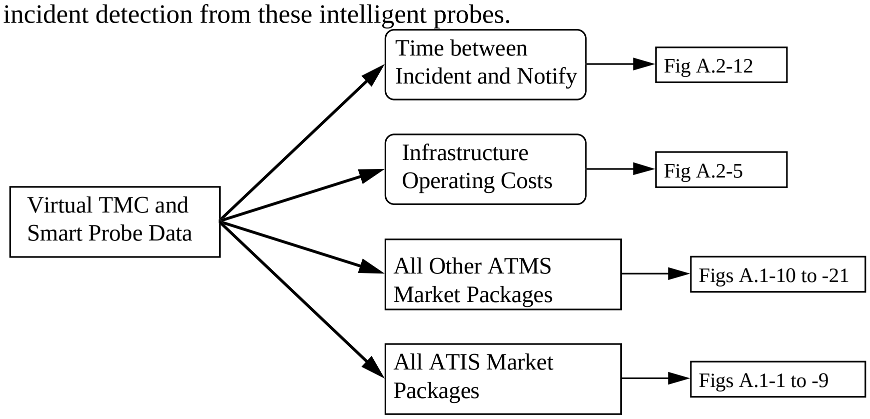

Figure A.1-21: Metrics from Virtual TMC and Smart Probe

A.1.3 Advanced Public Transportation Systems (APTS) Market Bundle

Seven market packages are proposed in the advanced public transportation system (APTS) market bundle. These market packages cover various public transportation management and service provision strategies. Perhaps the most basic market package for improving transit operations and management in real time is the transit vehicle tracking package, described in Figure A.1-22. This package allows for real-time vehicle location monitoring, scheduling, and dispatch, resulting in direct benefits to the user including: reduced transit travel time variability and travel times. For the transit fleet operators, automation of many operations management functions may yield reductions in operating and administrative costs and improvements in manpower productivity. These efficiency-related improvements to the transit operator are possible by the market package’s capability for real-time control of transit vehicle routing and scheduling.

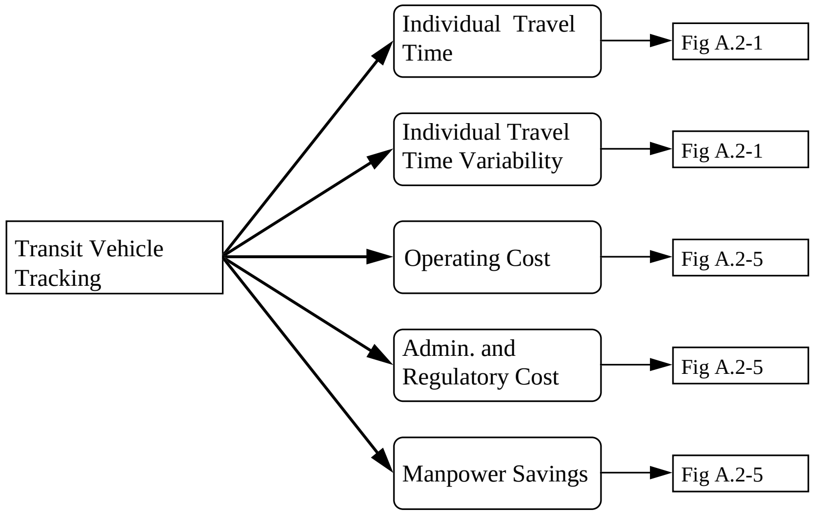

Figure A.1-22: Metrics from Transit Vehicle Tracking

Figure A.1-23 and Figure A.1-24 show the direct benefits of operations-related market packages for fixed-route and demand-responsive services, respectively. These packages are designed to automate or provide support for many of the supervisory and planning functions carried on at a transit agency, including driver assignment, vehicle routing, and vehicle scheduling. Improvements in vehicle routing and scheduling may result in reductions in travel times for transit passengers, including reductions in waiting times by increasing route frequencies and reductions in access and egress times by more efficient vehicle routing. For the transit fleet operators, automation of many operations planning functions may yield reductions in operating and administrative costs and improvements manpower productivity.

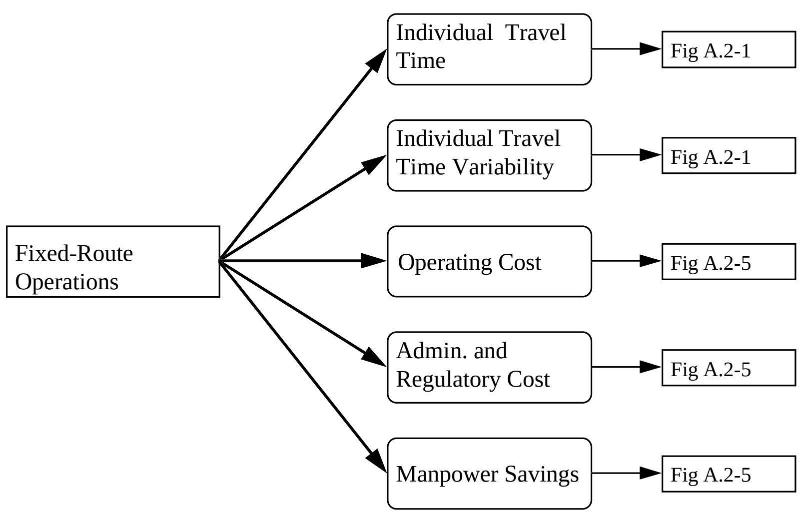

Figure A.1-23: Metrics from Fixed-Route Operations

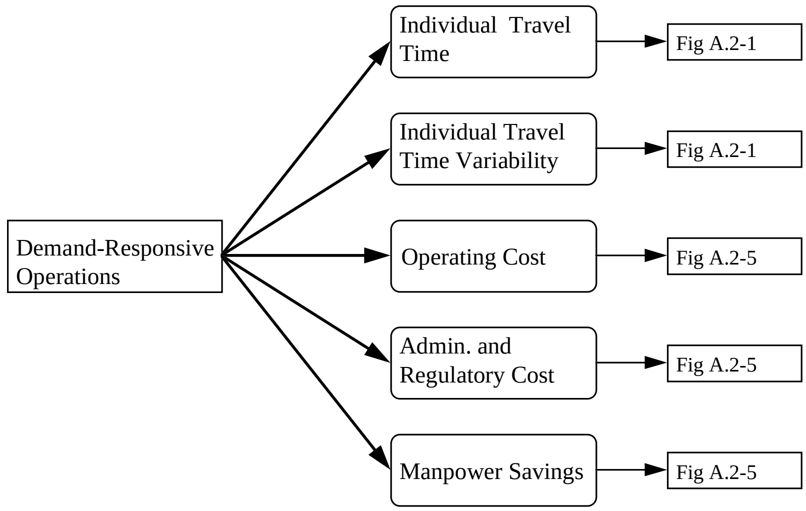

Figure A.1-24: Metrics from Demand-Responsive Operations

The passenger and fare management market package, shown in Figure A.1-25, may result in benefits to both transit operators as well as transit passengers. By handling financial transactions electronically, administrative and management costs associated with these transactions may be reduced. For the transit passenger, the ease of such electronic fare payment, using debit- or credit-type smart cards, will reduce the inconvenience of carrying change, thereby increasing the utility of travel and, in some cases, even the direct cost of travel. In addition, sensors may be used to automatically collect information on passenger loads, resulting in more effective use of transit labor. Vehicles may also be dispatched in response to critical loading situations, improving vehicle productivity and enhancing system performance.

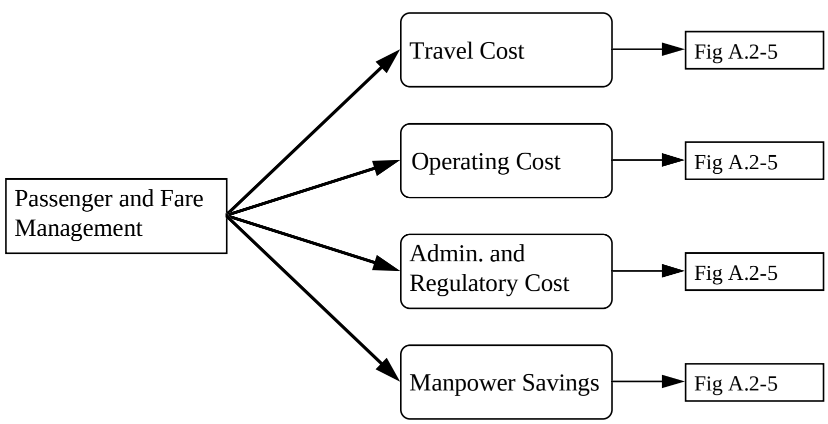

Figure A.1-25: Metrics from Passenger and Fare Management

A transit security market package has been included to provide security for transit passengers both on board the vehicle as well as in parking areas, stations, stops, and other transit-related areas. In this case, passenger activity in these locations can be monitored, and devices can be installed to notify appropriate personnel about dangerous or potentially hazardous situations. The impacts of this market package are shown in Figure A.1-26, and include: a potential reduction in security-related incidents due to increased monitoring, as well as faster detection and response to incidents if and when they occur.

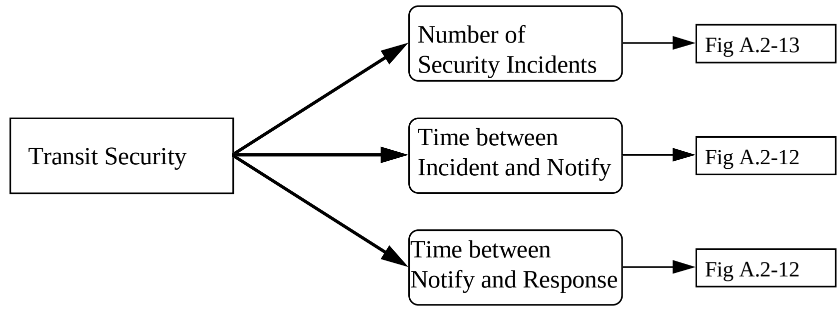

Figure A.1-26: Metrics from Transit Security

In a similar way as the operations planning market package, the transit maintenance market package (as described in Figure A.1-27) would serve to automate maintenance functions. This would include on-board vehicle condition monitoring, so as to avoid break-downs that may occur in normal revenue service. Administratively, the automation of the maintenance functions would also serve to reduce management costs. In the maintenance program, tracking of vehicle maintenance requirements and automated scheduling of maintenance tasks may also increase the productivity of both the vehicle fleet and the maintenance effort.

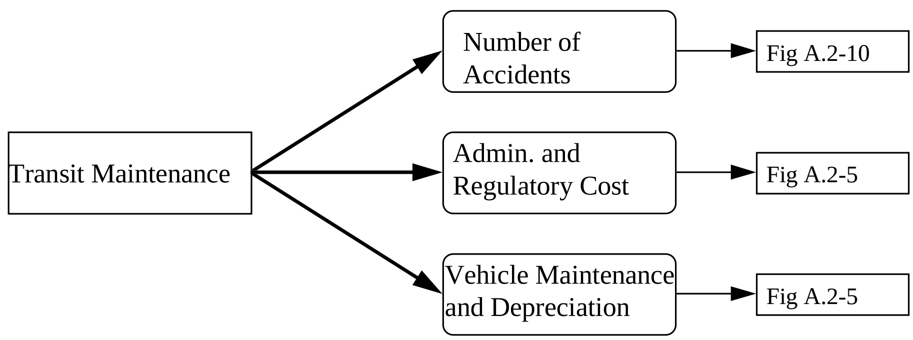

Figure A.1-27: Metrics from Transit Maintenance

Finally, the multi-modal coordination market package allows transit and traffic management to share information, particularly regarding signal priority for transit vehicles. Such priority, typically involving extending the green phase or shortening the red phase on a signal, may yield reductions in transit travel time and improvements in the reliability of transit services. In addition, the effective person-carrying capacity of the traffic network may also be improved by such priority systems. These benefits are indicated in Figure A.1-28.

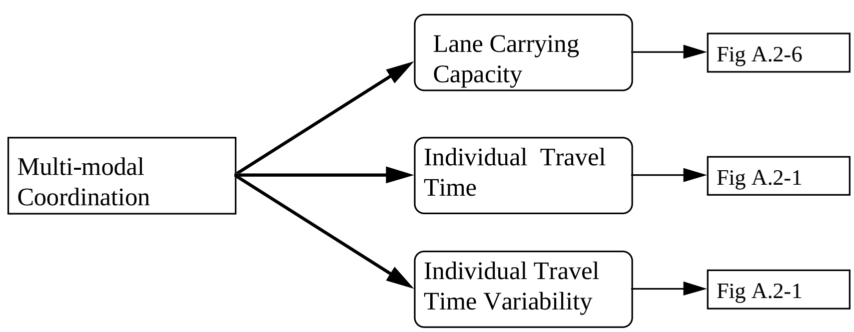

Figure A.1-28: Metrics from Multi-modal Coordination

A.1.4 Commercial Vehicle Operations (CVO) Market Bundle

The commercial vehicle operation (CVO) market bundle describes those market packages that improve commercial fleet management and safety. The first market package, fleet management, and its related benefit metrics are shown in Figure A.1-29. By tracking vehicle locations, travel condition and fleet location information is delivered to fleet managers to coordinate vehicle movements and improve travel times. Similar improvements in vehicle dispatching and routing can also affect vehicle and driver productivity. Finally, as this service will automate at least part of the fleet dispatching and control function, there may be reduced CVO administrative costs.

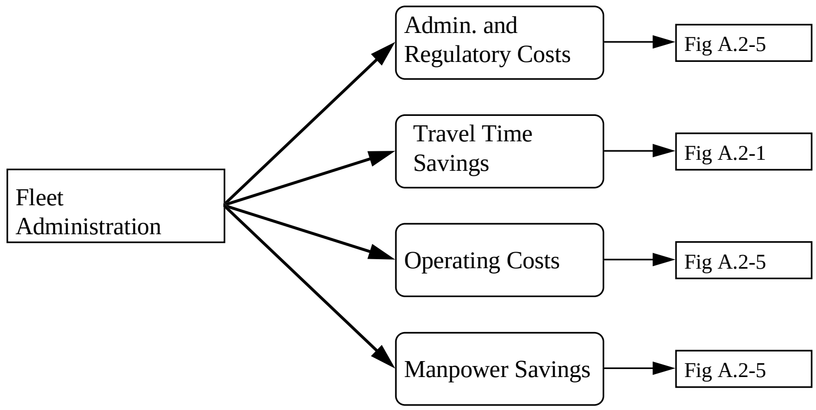

Figure A.1-29: Metrics from Fleet Administration

The freight administration market package provides real-time tracking and monitoring of cargo condition. Cargo condition is continuously monitored, and any changes in cargo condition are reported both to the driver and to the fleet manager. In this way, benefits may be realized by preventing or minimizing damage or other adverse conditions among the freight. By tracking material movements, fleet managers may also be able to reduce some operating and fleet management costs (as for the fleet management market package). These benefits are shown in Figure A.1-30.

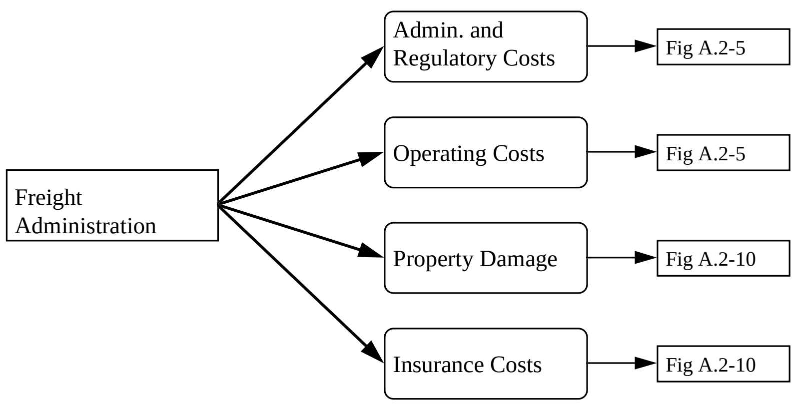

Figure A.1-30: Metrics from Freight Administration

An electronic clearance, commercial vehicle administrative processes, and international border electronic clearance market package are also included in the architecture, allowing commercial vehicle operators and fleet managers to automate the purchase of credentials and to pre-clear vehicles at borders. While the potential level of benefits varies, the benefits of these market packages, as shown in Figure A.1-31 through A.1-33, respectively, include a direct reduction in CVO administrative costs through automation of the acquisition of necessary CVO credentials. For commercial vehicles and their drivers, automating pre-clearance activities has the effect of reducing travel delays and will improve the cost-effective use of drivers and vehicles.

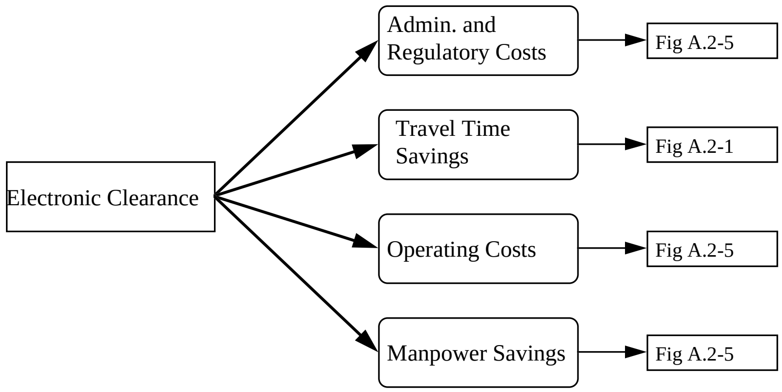

Figure A.1-31: Metrics from Electronic Clearance

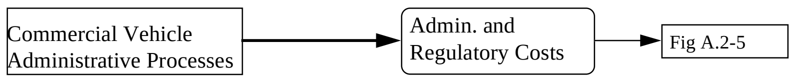

Figure A.1-32: Metrics from Commercial Vehicle Administrative Processes

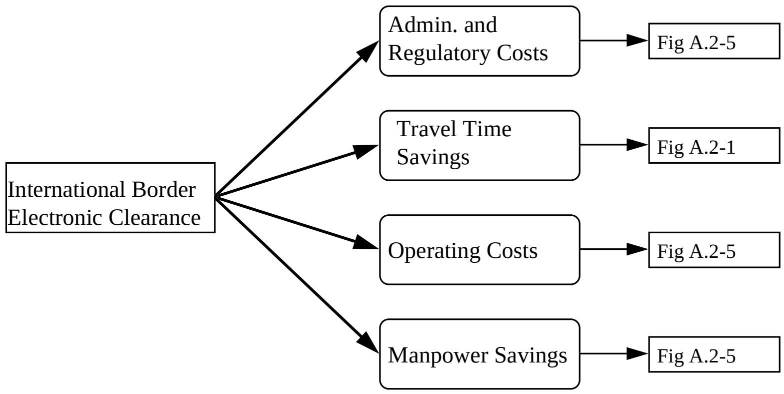

Figure A.1-33: Metrics from International Border Electronic Clearance

A weigh-in-motion market package allows commercial vehicles to be weighed at normal operating speeds, reducing the delays typically associated with the current weighing and inspection process. Figure A.1-34 shows that this may have the effect of reducing travel times, associated administrative costs (both commercial and public), and eliminating unnecessary travel delay. As a result, commercial vehicles and drivers can be used more productively, yielding lower operating costs and manpower savings.

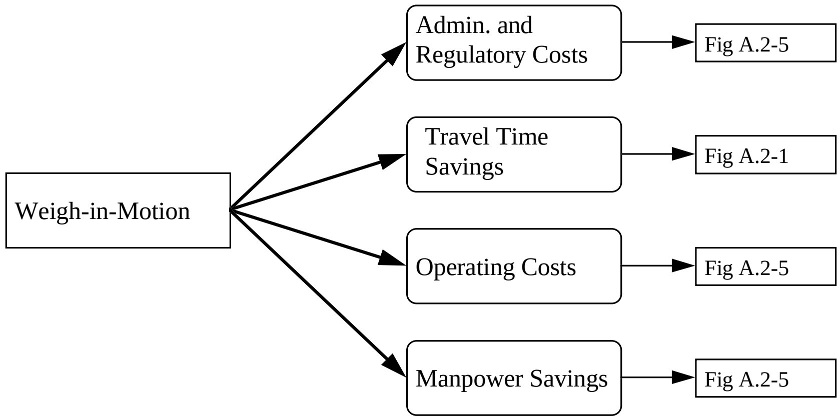

Figure A.1-34: Metrics from Weigh-in-Motion

Two market packages in the architecture cover the safety aspects of commercial vehicle operations. Both packages are intended to reduce commercial vehicle accidents and improve vehicle condition monitoring, resulting in improved vehicle maintenance. The benefits of a roadside safety inspection market package are illustrated in Figure A.1-35. In this case, the safety of a commercial vehicle may be inspected as it passes a roadside station, without the need to stop the vehicle. This service, then, also provides cost savings as those noted for the electronic clearance market package, including: reduced vehicle delay, lower operating and manpower costs, and reduced CVO administrative costs. A second package allows for on-board vehicle safety monitoring, as indicated in Figure A.1-36. This market package improves the level of safety of commercial transport, reducing the number of CVO accidents and assisting with vehicle maintenance.

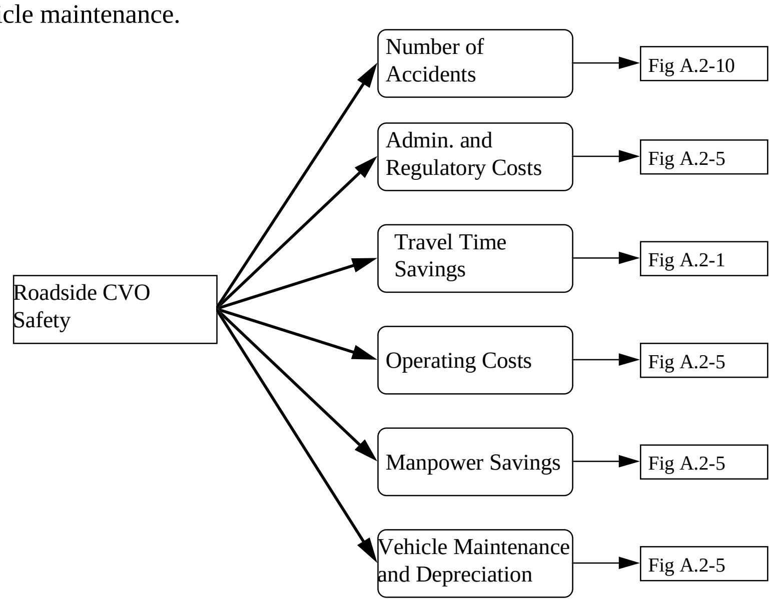

Figure A.1-35: Metrics from Roadside CVO Safety

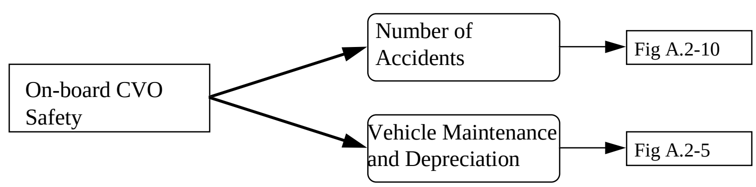

Figure A.1-36: Metrics from On-board CVO Safety

Direct improvements in commercial vehicle maintenance would be assisted by the CVO fleet maintenance market package, shown in Figure A.1-37. The functions in this market package allow fleet managers to monitor vehicle condition and to request and automatically schedule particular maintenance functions. This in turn may result in lower administrative costs, improved vehicle maintenance and, in the long term, more safety and productivity from the commercial vehicle fleet.

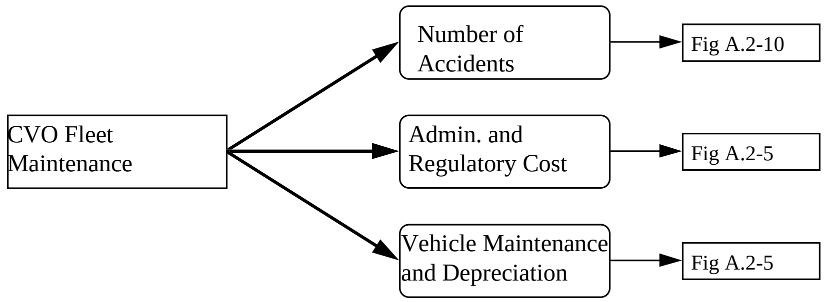

Figure A.1-37: Metrics from CVO Fleet Maintenance

Finally, Figure A.1-38 conveys the benefits associated with management of hazardous materials (HAZMAT) transport. In this package, these hazardous materials are continuously monitored on board the vehicle, and any changes in condition are reported to both the driver and the fleet manager. In this way, benefits of this market package may be realized by preventing material-related incidents, or, should an incident occur, providing accurate location and material information to response units. This will hasten the response to the incident, and ensure that the severity of the incident is minimized by issuing a response that is appropriate to the type of material involved.

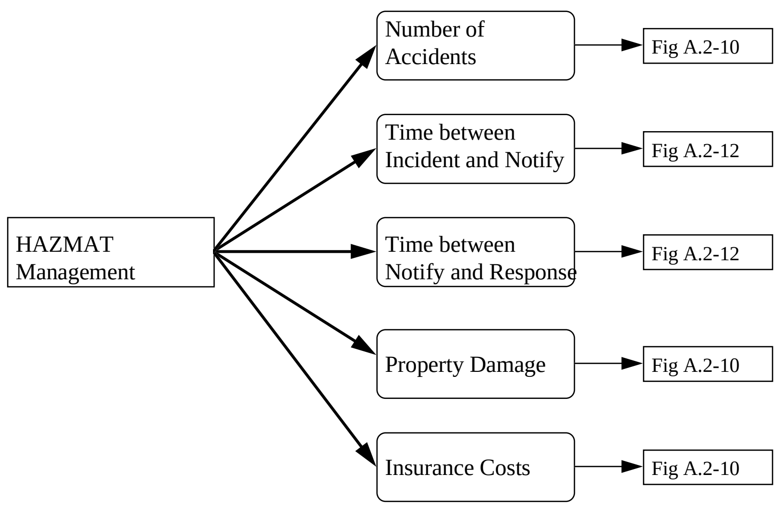

Figure A.1-38: Metrics from HAZMAT Management

A.1.5 Emergency Management (EM) Market Bundle

A number of benefits are possible by improving the emergency management capabilities of the road network. This may be done by enhancing emergency response to incidents, as well as improved management of the emergency services themselves. First, as shown in Figure A.1-39, an emergency response market package may provide quick or even automatic notification of the proper authorities in the case of an emergency in the road network, reducing administrative and regulatory costs. Faster routing and response to emergency calls may result in reduced incident response times may be reduced, and appropriate services may be dispatched to the scene, thereby indirectly reducing the severity of the incident.

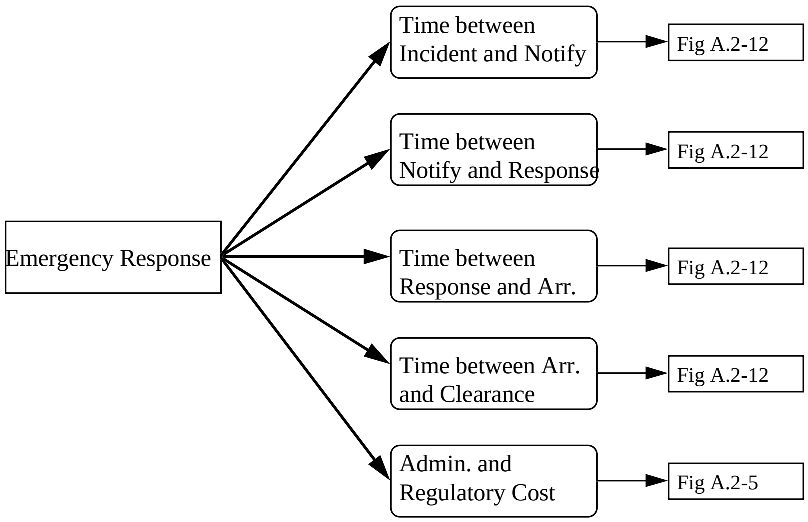

Figure A.1-39: Metrics from Emergency Response

In addition, the architecture includes an emergency vehicle routing market package to enhance routing of vehicles to emergencies. This market package allows for real-time local signal priority and route guidance for emergency vehicles to speed their response. As with the previous package, this may result in reduction of incident response times, and a corresponding (but indirect) reduction in incident severity. Also, for emergency managers, improved fleet utilization is possible through such time savings and fleet allocation. These benefits are shown in Figure A.1-40.

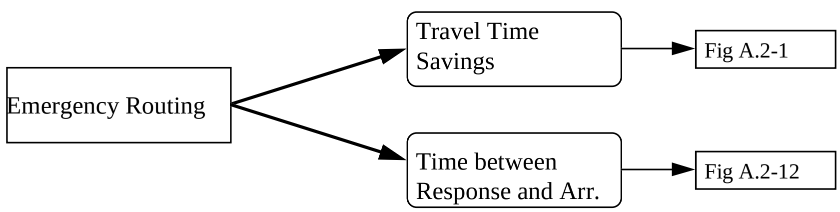

Figure A.1-40: Metrics from Emergency Vehicle Routing

Finally, the mayday support market package, shown in Figure A.1-41, allows for notification of the proper authorities when drivers are involved in an incident or accident. In this case, travelers can manually or automatically notify the appropriate personnel about the accident or about potentially hazardous situations. The impacts of this service include a potential reduction in safety-related incidents, and, if an incident should occur, these services provide real-time information to emergency personnel to respond more quickly to the incident.

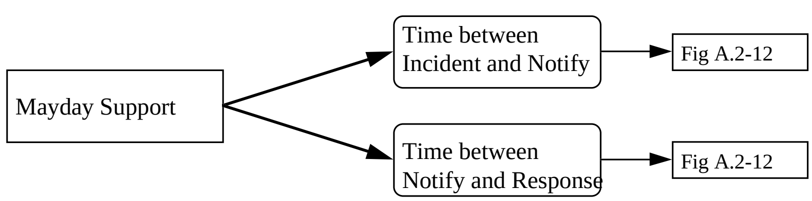

Figure A.1-41: Metrics from Mayday Support

A.1.6 Advanced Vehicle Safety Systems (AVSS) Market Bundle

The advanced vehicle safety system (AVSS) market bundle includes a number of market packages that affect individual vehicle and driver safety, and may enhance overall system safety. At the lowest level of functionality, the vehicle safety market package provides a continuous vehicle diagnostic capability, so that the driver may be warned of potential hazards with the on-board systems. This, in turn, may obviously result in both a reduced number of accidents and reduction in accident severity, as the driver may take appropriate action in response to such warnings. These benefits appear in Figure A.1-42.

Similar benefits may also be noted from the driver safety monitoring market package. In this case, the physical fitness of the driver may be determined and appropriate warnings or control actions taken to maintain vehicle and driver safety. Benefits of such a package, indicated in Figure A.1-43, include a decrease in the number of incidents and a reduction in accident severity, if the driver can take some corrective action.

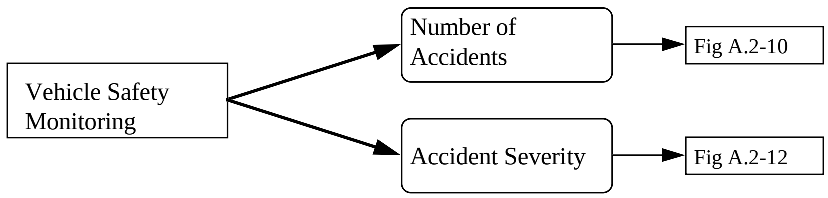

Figure A.1-42: Metrics from Vehicle Safety Monitoring

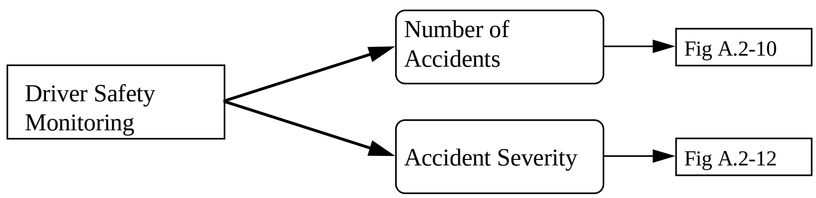

Figure A.1-43: Metrics from Driver Safety Monitoring

A similar set of benefits metrics apply to many of the safety warning market packages, including the longitudinal safety warning (Figure A.1-44), lateral safety warning (Figure A.1-45), and intersection safety warning (Figure A.1-46). In each of these market packages, on-board sensors would have the capability to detect potential hazards around the vehicle. In the case of intersection safety warning, infrastructure-based sensors may also be used. In all these cases, the market package would warn the driver of hazardous conditions to avoid accidents or reduce their severity.

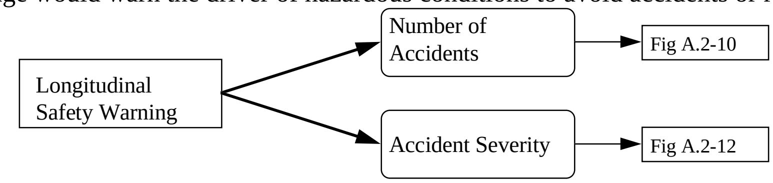

Figure A.1-44: Metrics from Longitudinal Safety Warning

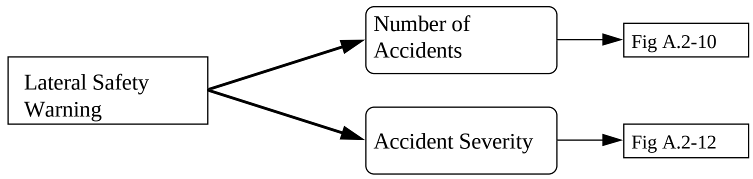

Figure A.1-45: Metrics from Lateral Safety Warning

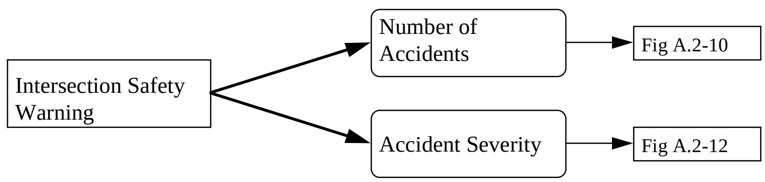

Figure A.1-46: Metrics from Intersection Safety Warning

The architecture also includes a market package for pre-crash restraint deployment. In this case, the market package allows for on-board sensors to detect potential hazards in front or behind the vehicle (i.e., in the longitudinal direction), or on the side of the vehicle. If an accident is determined to be imminent, a pre-crash restraint deployment system is automatically activated, thereby reducing the accident severity for the passengers of the vehicle. Most directly, Figure A.1-47 shows that accident severity may be affected by such a package.

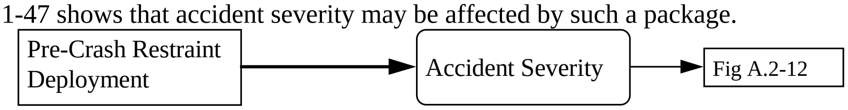

Figure A.1-47: Metrics from Pre-Crash Restraint Deployment

Other on-board systems may be used to enhance driver visibility, and thereby improve driving safety. This is done by enhancing visibility in inclement weather, at night, etc. A driver visibility improvement market package, shown in Figure A.1-48, allows drivers to see potential hazards earlier and respond appropriately. This service may thus reduce the number and the severity of accidents.

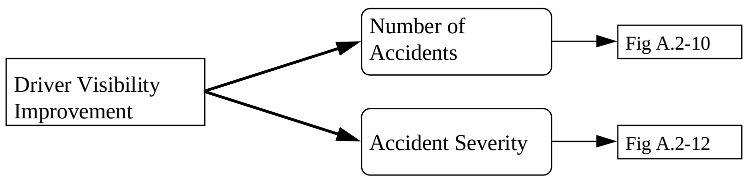

Figure A.1-48: Metrics from Driver Visibility Improvement

An advanced vehicle longitudinal control system could be used to maintain safe speeds and following distances automatically. Benefits of such a market package are shown in Figure A.1-49. Such a system could potentially reduce the number of longitudinal accidents between vehicles and reduce the severity of these accidents. In addition, this package may logically change the effective vehicle headways, resulting in increased lane-carrying capacities.

Another automated system providing related safety benefits is the advanced vehicle lateral control package. In this system, the steering function may be automated, allowing the vehicle to hold position within a lane. As above, the potential benefits (identified in Figure A.1-50) include reduced accidents, reduced accident severity, and improvements in lane-carrying capacity.

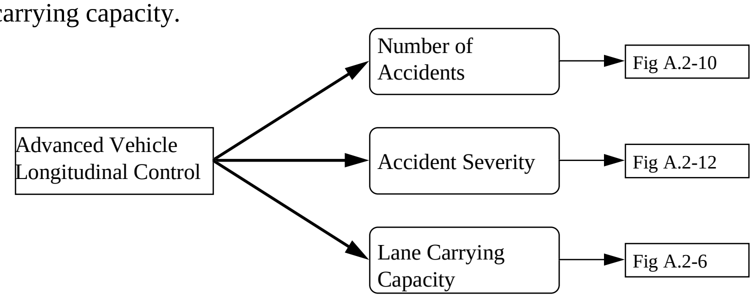

Figure A.1-49: Metrics from Advanced Vehicle Longitudinal Control

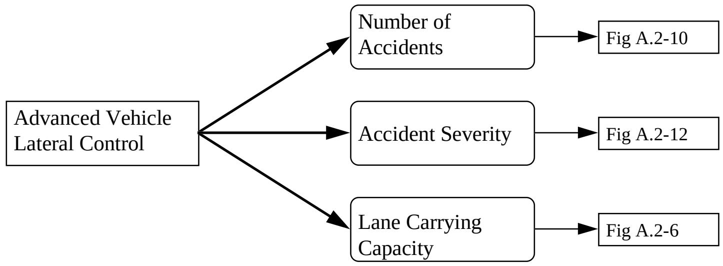

Figure A.1-50: Metrics from Advanced Vehicle Lateral Control

The intersection collision avoidance market package would provide driver warnings about potential cross traffic at an intersection, allowing the driver to take appropriate action or even allowing automatic vehicle control to avoid an accident at an intersection. Figure A.1-51 suggests that such a system would reduce accidents in intersections and decrease accident severity when accidents do occur. However, one might also expect that, as a result of the improvements in safety at these intersections, the effective capacity in these intersections may also increase.

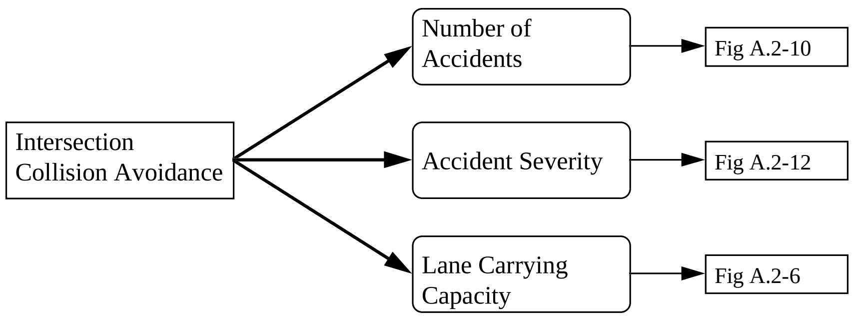

Figure A.1-51: Metrics from Intersection Collision Avoidance

In a more advanced safety system, driving may be automated on some highway segments, allowing both "hands-off" and "feet-off" driving over such automated roads. As with the previous market packages, the potential benefits of such a system include safer highway operation, by reducing situations in which incidents might occur. In such a case, automated driving can have a substantial impact on automobile safety, including the frequency of traffic accidents and their severity. In addition, this market package may yield significant improvments in roadway capacity. These impacts are identified in Figure A.1-52.

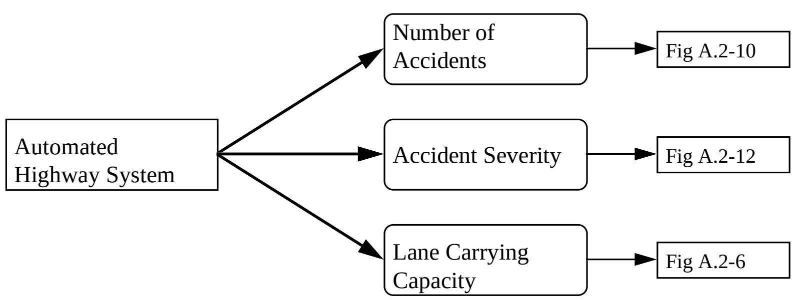

Figure A.1-52: Metrics from Automated Highway System

A.1.7 ITS Planning Market Package

Finally, but by no means the least, is the ITS planning market package. This package assembles data and information about ITS deployments, their costs and benefits, to planners. With the aid of computer decision support services, cost-effective and institutionally viable ITS projects and programs can be developed. In this way, the ITS planning market package serves all other market packages in the architecture, as shown in Figure A.1-53.

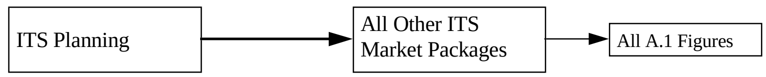

Figure A.1-53: Metrics from ITS Planning

A.2 Connection of Transportation System Metrics to ITS Goals

A.2.1 Introduction

Table 6.1-1 gives a set of metrics that best reflect the six ITS goals of increasing mobility and transportation system efficiency, improving safety, reducing energy consumption and environmental costs, increasing economic productivity, and enhancing the ITS market. The previous section has described logic flow diagrams which connect the Joint Team's market packages with a set of direct impacts on the transportation system. These metrics, in turn, may be logically connected to the goals to reflect how deployment of these market packages may result in the intended objectives of the ITS program. In this section, the transportation system metrics suggested in the figures in Section A.1 are connected to these ITS goals.

Each of the logic flow diagrams in this section include arrows on top of the box showing an implied direction of the dependence. For example, reduced travel times will result in a increase utility of travel. These dependencies in direction are noted when the direction of the dependence is reasonably unambiguous. However, there is disagreement in the transportation community about the direction of dependence on some changes in metrics, and in such cases, the direction of an effect is not shown with an arrow within the box. Yet there is some logical dependence that needs to be considered in these diagrams.

There are two other points regarding these diagrams that should be noted before beginning this discussion. First, to avoid simply redundant figures with arrows pointing in opposite directions, there is only one direction of dependence given for the first (i.e., left-most) metric on a figure. For example, travel times might be shown to decrease, and the resulting impacts noted in that figure, such as higher travel utility, correspond to that assumption. At the same time, one might also expect that if travel times increase, the exact opposite effect would occur; i.e., travel utility would decrease. This opposite figure, however, is not shown; it is left to the imagination of the reader to reverse the arrows for each metric in such circumstances.

The reader might also notice that in some instances, the impacts of some transportation system metrics are circular. For example, it is well known that higher traffic volumes produce greater congestion, and thus slower travel times, on the road network. However, higher travel times also decrease the travel utility, thereby reducing the demand for travel altogether. In this case, higher travel times also yield lower traffic volumes, resulting in some *inter-dependence* between travel times and traffic volumes. When there is a change in travel times, there results a form of equilibrium in which traffic volumes and travel times reach more or less "predictable" levels. The circular nature of several of these diagrams shows that elements work together to create this equilibrium.

A.2.2 Benefits Flow Diagrams: Metrics to ITS Goals

One of the feature benefits of many market packages is a reduction in vehicle, driver and passenger travel time. The logical connections of travel time to other metrics and ITS goals are shown in Figure A.2-1. Reductions in individual travel time, and travel time variability, will result in an increase in the travel utility: the “generalized cost” to the traveler of traveling will decrease. At the same time, these improvements in travel time characteristics may cause some travelers to change their departure time from the origin or the arrival time at the destination, resulting in faster delivery times and corresponding increases in either leisure time or work time. The net effect of this faster delivery time, then, will be a slight improvement in individual productivity. System-wide gains in productivity from time savings may also be realized, as indicated by the travel time savings metric in the figure.

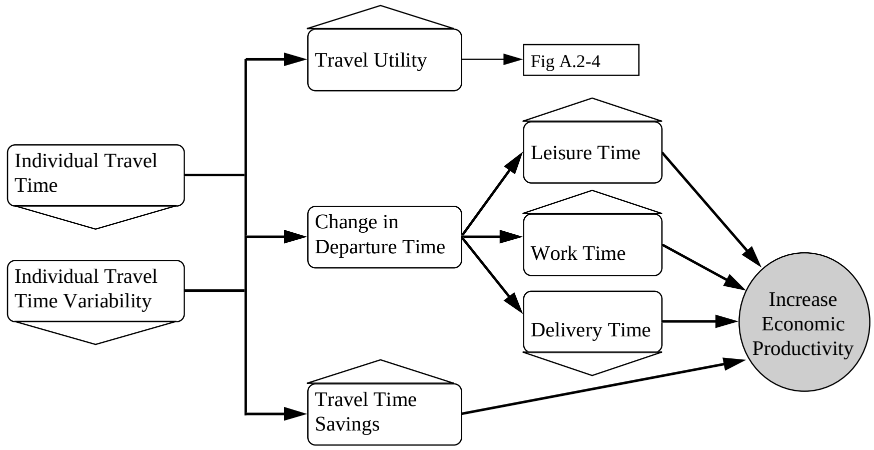

Figure A.2-1: Metrics of Travel Time and Travel Time Variability

Another important transportation system metric is traffic congestion measured through individual or vehicle delays. Recurring congestion or incident-related delay directly affects the travel time and travel time variability for individual drivers and passengers. System-wide, these delays also may effect the larger amount of travel time in the transportation network as a whole. These direct connections are shown in Figure A.2-2.

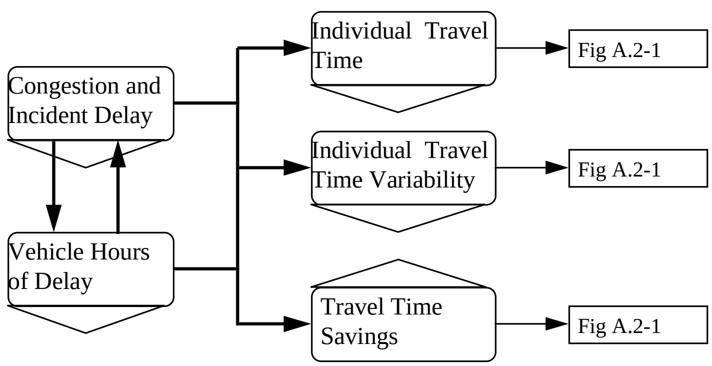

Figure A.2-2: Metrics of Individual and Vehicle Delay

Figure A.2-3 shows the implications of increased use of transit and HOV modes, and increases in average vehicle occupancy. Such metrics are direct measures of the level of transportation system efficiency, and, indirectly, of personal mobility. Higher mode shares for transit and HOV mean higher vehicle occupancies, resulting in lower VMT and lower total traffic volumes (all other things being equal).

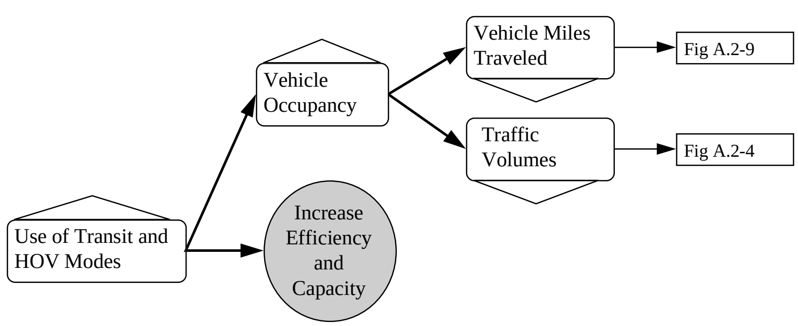

Figure A.2-3: Metrics of HOV and Transit Time, HOV and Transit Utility

Changes to benefits metrics resulting from an increase in the utility of travel are shown in Figure A.2-4. An increase in the travel utility directly causes an increase in mobility. This improvement in mobility may also to cause individuals to increase the total number of trips taken (i.e. induced travel). Taken at the aggregate, higher induced travel results in higher levels of VMT and also an increase in traffic volumes; these higher traffic volumes will in turn increase volume-to-capacity ratios. Back at the level of the individual, improvements in the value of travel, coupled with better information on travel and activity options, may also result in trip-end-activities that have higher value to the individual. Such benefits of activities also can be included in the benefits of improved mobility.

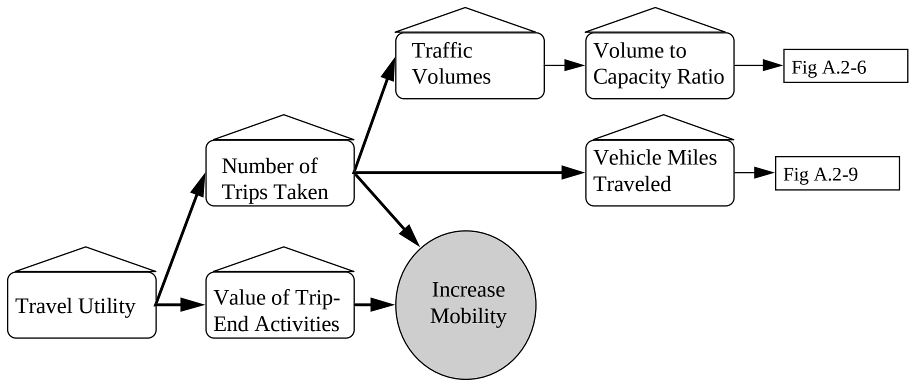

Figure A.2-4: Metric of Travel Utility

Many of the market packages in turn may result in cost savings direct to the traveler or to fleet operators (i.e. transit, emergency vehicle, or commercial vehicle operators). The benefits of such cost savings are indicated in Figure A.2-5. Reduction in travel costs (i.e. to the traveler) result in higher utility of travel. Cost savings for firms and fleet operators may take the form of administrative and regulatory costs, operating costs, travel time savings, manpower savings, improved vehicle maintenance and more favorable vehicle depreciation. By removing such expenses from transportation requirements, these resources may be re-allocated to other activities, implying improvements in individual as well as corporate economic productivity.

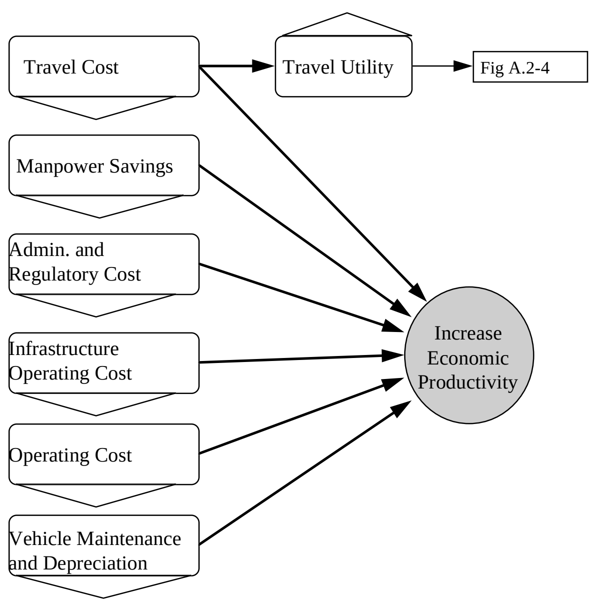

Figure A.2-5: Metrics of Travel Costs and Cost-related Savings

Several of the ITS market packages may result in changes in lane-carrying capacity; such impacts are shown in Figure A.2-6. When there is considerable improvements in the carrying capacity of the road network, resulting in reductions in volume-to-capacity ratios. This ratio serves as a suitable proxy for congestion. As such, reductions in volume-to-capacity ratios may result in lower congestion-related delay, vehicle hours of delay, and queue lengths.

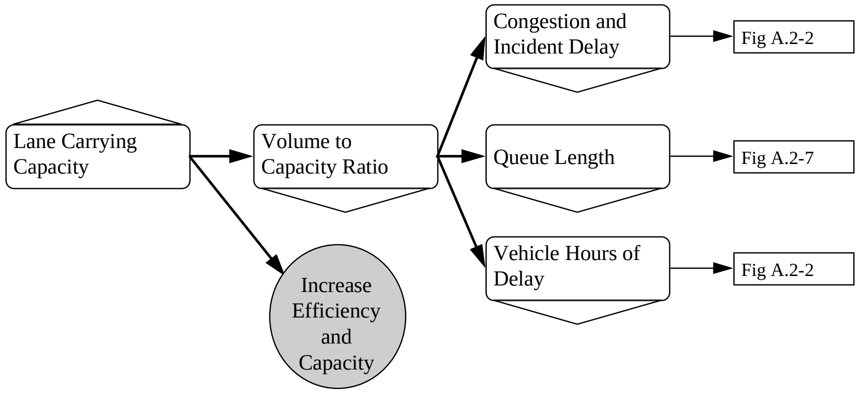

Figure A.2-6: Metric of Lane-Carrying Capacity

Decreases in traffic queue lengths will have connections to other travel metrics, as shown in Figure A.2-7. Because of shorter queue lengths, the number of starts and stops of vehicles will logically decrease as fewer cars must wait in the queue. Also, queue lengths are a valid indicator for vehicle delays and congestion levels as a whole, with the association that shorter queue lengths imply reduced levels of congestion and incident-related delay. Finally, bottlenecks in the network also consume much needed system capacity, so that shorter queue lengths may result in greater system capacity and a corresponding increase in the effective system capacity.

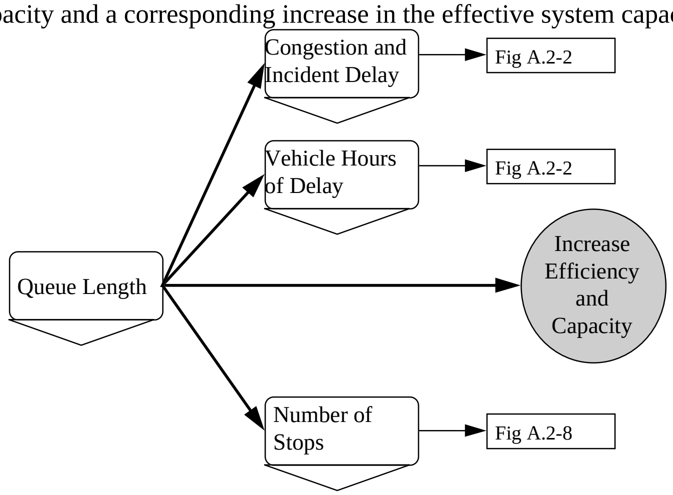

Figure A.2-7: Metric of Queue Length

Figure A.2-8 shows the dependencies of travel metrics on the number of stops in the network. For travelers in the network, stops can add a considerable amount of time and variability to travel times. Thus, a reduction in the number of stops may reduce travel times and their associated variability. In addition, each time a vehicle stops, decelerations and accelerations are necessary to resume normal travel speed. Reducing these cycles, then, implies that vehicle engines may operate at higher efficiency, resulting in lower fuel consumption and lower emissions. Lower fuel consumption is a direct measure of energy consumption, and lower emissions rates are directly responsible for improvements in ambient air quality. Finally, lower long-term vehicle operating and maintenance costs may also result from more efficient operation of vehicle engines.

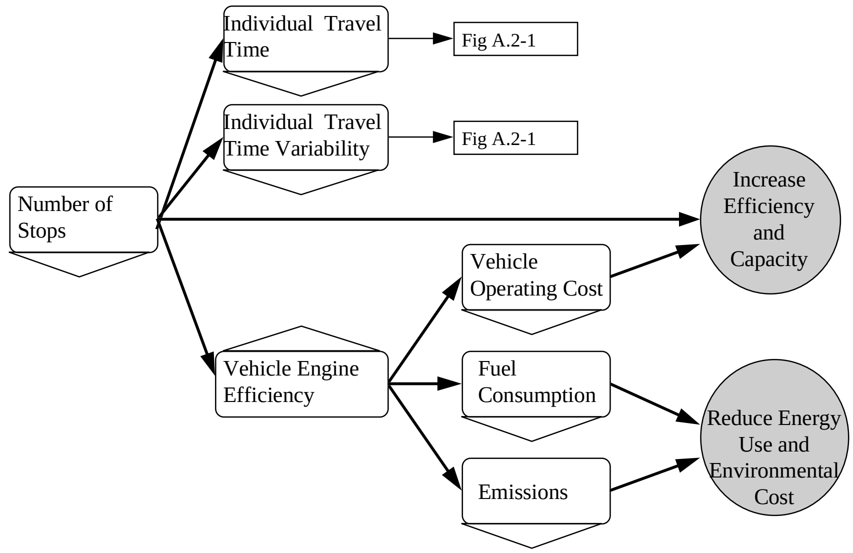

Figure A.2-8: Metric of Number of Stops

Vehicle miles traveled (VMT) serves as a primary measure of the volumes of traffic in a network. Figure A.2-9 shows the logical implications of lower VMT, including the obvious measures of lower vehicle emissions, lower fuel consumption, and a reduction in the number of accidents. Moreover, reductions in VMT often result from decreases in total traffic volumes. Through these metrics, the reduction of VMT may fulfill four major ITS goals: enhanced environment (through improved air quality), reduced energy usage, improved safety, and increased transportation system efficiency.

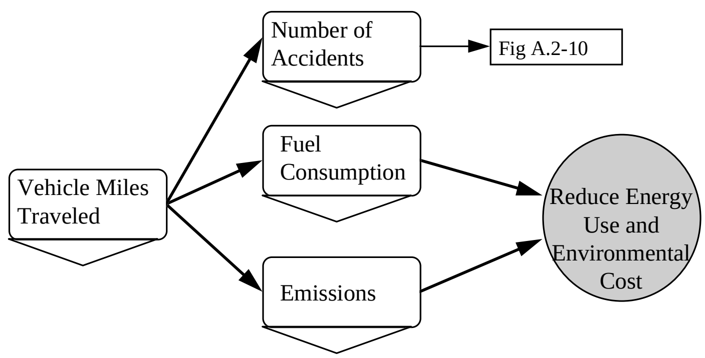

Figure A.2-9: Metric of Vehicle Miles Traveled (VMT)

A number of safety measures associated with the market packages will yield reductions in the number of accidents or other incidents on the road network. Figure A.2-10 shows the logical connections of reduced accidents in the traffic network. Most directly, a reduced number of accidents will reduce the size and number of bottlenecks in the network. A corresponding reduction in exposure to accidents and incidents is also expected, since fewer travelers will have such exposure. A reduction in the number of accidents also implies that there are less property losses, injuries, and fatalities, achieving the ultimate ITS goal of improved travel safety. Economically, the losses due to property damage and casualties may also be counted as benefits, in terms of reduced down time for workers and lower medical and insurance costs. This will help realize the goal of improving economic productivity.

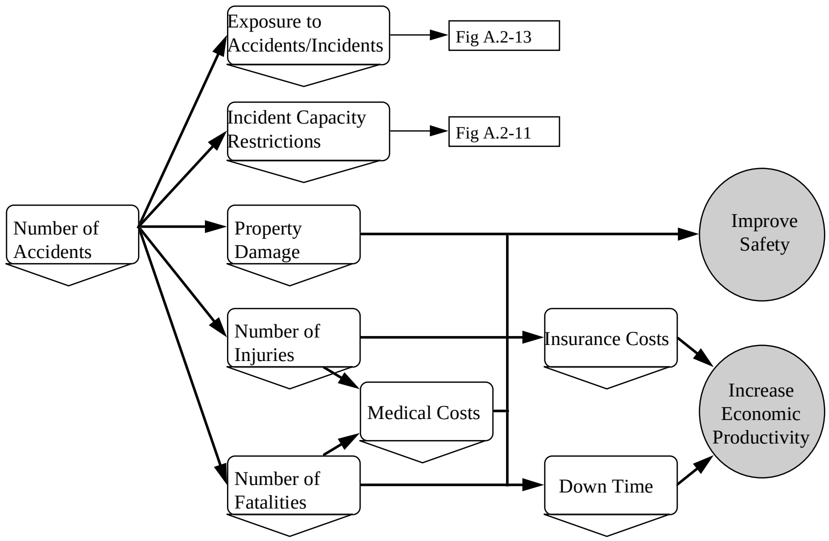

Figure A.2-10: Metric of Number of Accidents

When such accidents and incidents occur, significant reductions in roadway capacity can occur. This loss of capacity can result in major bottlenecks in traffic, with considerable queuing and delay. Figure A.2-11 gives the impacts associated with reducing incident-related capacity reductions: reductions in delay, queue lengths, and vehicle stops.

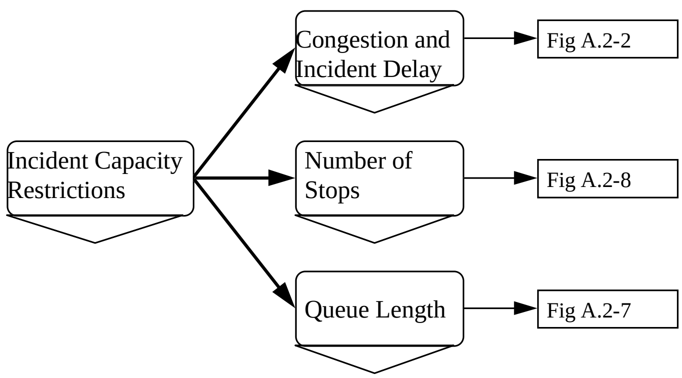

Figure A.2-11: Metrics of Incident Capacity Restrictions

In a similar manner, a reduction in incident response times duration should yield lower exposure to such incidents, improvements in incident-related capacity and a reduced severity of injury from the incident, as shown in Figure A.2-12. Reductions in the severity of the accident will directly affect the amount of property damage, the severity of injuries, and even the number of fatalities associated with the incident.

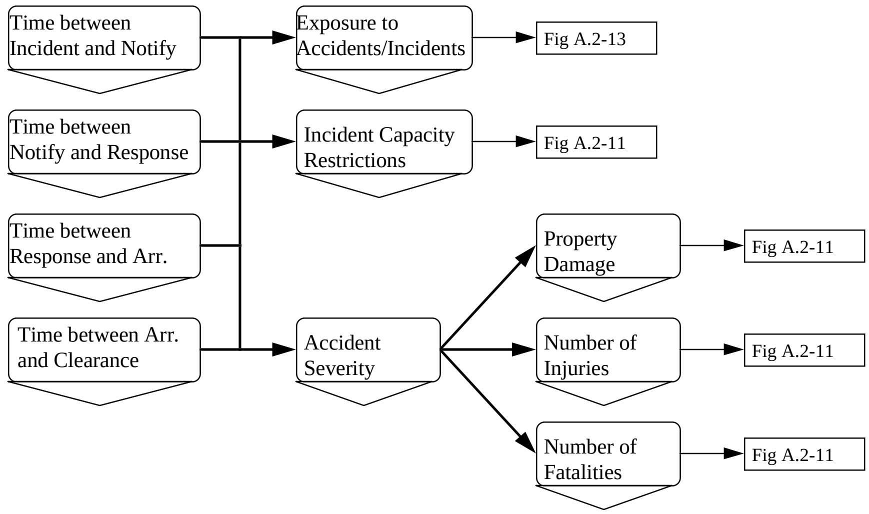

Figure A.2-12: Metrics Associated with Incident Duration and Response

Finally, Figure A.2-13 shows changes in metrics based on improvements in personal travel security. A number of the market packages promote elements to either prevent security problems. Obviously, fewer security incidents will lead to lower exposure to such events. This lower level of exposure, then, in turn results in higher utility from travel. At the same time, lower exposure to accidents and incidents may also in turn result in some reduction in secondary accidents: in certain cases, secondary accidents may be a considerable source of incidents in the transportation network. In additon, fewer security incidents means an increase in transportation safety directly and also lower levels of property damage and personal injuries and fatalities.

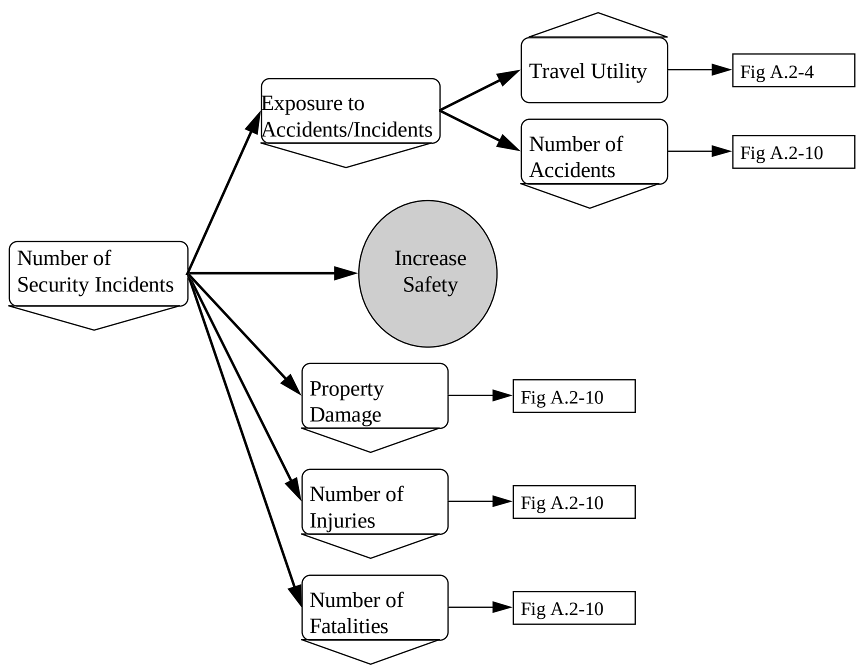

Figure A.2-13: Metrics Related to Security Incidents and Exposure to Accidents