ITS Mission Definition

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Executive Summary

The National ITS Architecture Mission Definition includes the system level concepts and requirements that document the fundamental needs which will be fulfilled by a successful ITS architecture. It provides a representation of the system which is useful for conveying the ideas for future improved transportation systems to the general public. The Mission Definition contains a concise mission statement explaining the purpose of the National ITS architecture. The mission is defined, based on ITS architecture goals and objectives, in such a manner that it can be accomplished across diverse operational scenarios and deployment timeframes. Levels of performance are specified which accomplish the mission, taking into account other system-level technical and non-technical constraints which influence the architecture development phases.

> *The Mission is the development of the National ITS Architecture. This architecture will facilitate the application of current and future technologies to improve the personal transportation experience and to improve the processes involved in moving people, goods, services and information throughout the country.*
>
> *The ITS architecture is the framework of interconnected subsystems which together provide the ITS user services through allocated functionality and defined interfaces. This architecture must be open and flexible to prevent unnecessary restriction to implementation choice and to accommodate the varied needs of the public and private sectors. At the same time, the architecture definition must be sufficiently precise to ensure a transportation and communication system design that is both compatible and interoperable across the nation*

Nationwide interoperability will ensure that a mobile user will be able to obtain traveler information or emergency assistance anywhere such a service is available using a standard interface. Since there may be several different types of technologies providing these services, compatibility ensures that these technologies will not interfere with each other.

The ITS architecture goals are summarized as follows:

- *Increase operational efficiency and capacity of the transportation system.*
- *Enhance personal mobility and the convenience and comfort of the transportation system.*
- *Improve the safety of the Nation's transportation system.*
- *Reduce energy consumption and environmental costs.*
- *Enhance the present and future economic productivity of individuals, organizations and the economy as a whole.*
- *Create an environment in which the development and deployment of ITS can flourish.*

Following the operational concept section, the operational requirements define the system processes, information flows, performance parameters, and technical and non-technical constraints which the ITS must incorporate, be developed from, and operationally satisfy. These requirements specify an initial system-level basis from which development of an ITS architecture can take place. Operational requirements are organized into system-level requirements, user requirements, performance requirements, "ilities", e.g., reliability and maintainability, and program requirements.

Appendix A presents an analysis of the security and privacy threats to an ITS system architecture. Its purpose is to raise the security and privacy awareness of the ITS community, e.g., developers, sponsors and stakeholders. The list of threats is not all-inclusive, but is only intended to indicate where possible abuses of the ITS could occur. A brief summary of possible security and privacy techniques that could be applied to counter some of these threats is also presented.

1.0 INTRODUCTION

The Mission Definition contains the system level concepts and requirements that document the fundamental needs to be fulfilled by a successful ITS architecture. It provides a representation of the system that is useful for conveying the ideas for future improved transportation systems to the general public. To define the ITS architecture mission, this document:

1. Provides a concise mission statement (Section 2.0: Mission Statement);

2. Defines how the mission is to be accomplished across the diverse operational scenarios and deployment timeframes. (Section 3.0: Operational Concept);

3. Specifies the level of performance needed to accomplish the mission, and other system-level technical and non-technical constraints which influence the succeeding architecture development phases (Section 4.0: Operational Requirements).

2.0 MISSION STATEMENT

The Mission is the development of the National ITS Architecture. This architecture will facilitate the application of current and future technologies, to improve the personal transportation experience, and to improve the processes involved in moving people, goods, services, and information throughout the country.

The ITS architecture is the framework of interconnected subsystems which, together, provides the ITS user services through allocated functionality and defined interfaces. This architecture must be open and flexible to prevent unnecessary restriction to implementation choice. The architecture must also accommodate the varied needs of the public and private sectors. At the same time, the architecture definition must be sufficiently precise to ensure a transportation and communication system design that is both compatible and interoperable across the nation.

3.0 OPERATIONAL CONCEPT

The operational concept describes how the ITS architecture satisfies the mission statement. The operational concept:

1. Derives the ITS architecture goals and objectives from the mission statement and ITS goals;

2. Defines architecture concepts and describes their relationship to the mission statement;

3. Identifies those who will fund, build, operate, maintain, and use the architecture elements;

4. Describes how users will interact within the architecture to accomplish the ITS architecture goals and objectives.

3.1 Goals and Objectives

The following statement describes the major goals of the national ITS program and its architecture:

> *Create a system that enhances transportation through the safe and efficient movement of people, goods, and information, with greater mobility and fuel efficiency, less pollution, and increased operating efficiency. The system must be accommodating and fair in serving the interests of government, individuals, and companies who desire to competitively develop and market transportation technologies.*

3.1.1 ITS Goals

Six ITS goals consistent with those presented in the Strategic Plan and National ITS Program Plan may be derived from the statement above:

1. **Increase operational efficiency and capacity of the transportation system.** A central goal of ITS is to better utilize the capacity and increase operational efficiency of the surface transportation system. In fact, this goal actually underlies and enables attainment of several of the other ITS goals. Reducing congestion, providing reliable information on which travelers can make better travel decisions, eliminating the delays of toll collection, and more traffic-responsive coordination of traffic lights all contribute to enhanced effective capacity and efficiency, as well as to general mobility, productivity, more efficient use of resources, and reduced environmental impact. A bit further out in time, the automated highway system (AHS) will contribute even more dramatically to increasing the effective capacity of our existing travel ways.

2. **Enhance personal mobility and the convenience and comfort of the transportation system.** Goal #1 makes a major contribution toward this, as will public transportation systems that are more convenient and cost-effective. New control systems will increase transit automation and predictability. Intermodal management services will improve connections between modal systems and increase trip end opportunities. Increased availability of high-fidelity traveler information will enable better informed travelers to make the best transportation choices.

3. **Improve the safety of the Nation's transportation system.** There is need for safety improvement, particularly in overcoming human error in vehicle operation, preventing or reducing the severity of injuries in collisions, and enhancing traveler security in all transportation modes. Safety is a key consideration in the implementation of all ITS services, but the most dramatic gains are expected to derive from the Advanced Vehicle Control and Safety Systems.

4. **Reduce energy consumption and environmental costs.** Our ability to use energy more efficiently and reduce environmental costs will depend, in part, on the technologies applied through the ITS program. More efficient energy use and improved air quality can be achieved by ITS services which encourage public

transportation use, increase average vehicle occupancy, smooth traffic flow, and manage travel demand. Better use of existing transportation resources will positively impact land use by reducing requirements for new infrastructure.

5. **Enhance the present and future economic productivity of individuals, organizations and the economy as a whole.** Transportation is an integral part of nearly all productive processes, and making transportation more efficient (Goal #1) lets all these processes be more efficient. This applies as well to individuals in their daily lives: commuting, shopping, socializing. Thus more efficient routing, reduced travel times, and more efficient administration of the transportation system will enable productivity gains across the spectrum of the economy. This ITS architecture goal is an advancement of Goal 2 (mobility) which includes further demand adjustments to increase economic output.

6. **Create an environment in which the development and deployment of ITS can flourish.** This goal is distinct in that it directly addresses architecture issues rather than user service and design issues. The ITS architecture development effort is one of the principle steps that will facilitate the application of new technologies to surface transportation. The degree to which the architecture is open and facilitates standardization and inter-operability will foster active industry participation in the design, development, deployment, and operation of ITS subsystems.

Table 3.1.2-1 provides a more detailed delineation of the specific actions and objectives that can contribute to these broad ITS goals. Clearly there are tradeoffs among almost all of these objectives.

Table 3.1.2-1. ITS Development Objectives[1]

Increase operational efficiency and capacity of the transportation system

- Increase Operational Efficiency
- Increase speeds and Reduce stops
- Reduce delay at intermodal transfer points
- Reduce operating costs of the infrastructure
- Increase private vehicle occupancy and transit usage
- Reduce private vehicle and transit operating costs
- Facilitate fare collection and fare reduction/equity strategies
- Reduce freight operating costs and increase freight throughput

Enhance personal mobility, convenience, and comfort of the transportation system

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

Improve the safety of the Nation's transportation system

- Increase personal security
- Reduce number and severity (cost) of accidents, and vehicle thefts
- Reduce fatalities

Reduce energy consumption and environmental costs

- Reduce vehicle emissions due to congestion and fuel consumption due to congestion
- Reduce noise pollution
- Reduce neighborhood traffic intrusiveness

Enhance the present and future economic productivity of individuals, organizations and the economy as a whole

- Increase sharing of incident/congestion information
- Reduce information-gathering costs
- Increase coordination/integration of network operation, management, and investment
- Improve ability to evolve with changes in system performance requirements and technology

[1] Adapted from Daniel Brand, "Criteria and Methods for Evaluating Intelligent Transportation System Plans and Operational Tests" Transportation Research Record 1453, 1995 and other valued Stakeholder and Architecture Review team inputs.

3.1.2 Architecture Development Objectives

The ITS architecture defines an overall framework of integrated subsystems that can provide all of the services desired of the ITS. The objectives of this effort are as follows:

1. **To provide a framework for the definition of appropriate standards.** These standards insure national interoperability, so that vehicle equipment purchased anywhere will work throughout the nation. Standards increase the practicality of modularity in design and manufacture, and modularity based on appropriate standards permits the interchangability both within and among subsystems. In turn, this allows greater competition among equipment suppliers and insures that cities do not become captive to proprietary systems as well as broadens their options for follow-on upgrading or expansion. It also permits volume production and concomitantly lower costs.

2. **To provide the basis for integration among subsystems.** This reduces the need for duplicatory functions in different subsystems and thereby enhances reliability and reduces costs. This also insures the use of common informaion sources among subsystems

3. **To insure a high degree of flexibility in user choice.** Users can purchase only what they need, rcognizing that they are dealing with building blocks that can support a wide range of implementation options without losing the advantages of integration and standards, or foreclosing the option for future upgrading and expansion.

A set of objectives specific to the ITS architecture development effort can be derived from the system level National ITS Architecture goals. The overall statement of objectives is provided below. Table 3.1.2-1 further describes the objectives for ITS architecture development.

> *The objective of the ITS architecture development effort is to create an integrated system architecture whose component subsystems satisfy the ITS architecture goals, ensure nationwide compatibility and interoperability, support the necessary range of implementations, and allow for cost-effective expansion and modernization.*

3.1.2.1 Scenario-Specific Goals and Objectives

Clearly transportation needs are not uniform across the country. To aid in thinking about and analyzing the differing needs, three scenarios have been defined to distinguish urban, inter-urban, and rural characteristics. Specific goals and objectives have been defined that are responsive to the characteristics of the three scenarios and time frames. Table 3.1.2.1-1 lists the diverse characteristics that distinguish urban, inter-urban, and rural scenarios.

The *urban scenario* includes a large population center, with a surface transportation infrastructure that may not keep pace with increasing demand. Services that enable transportation system efficiency and demand management (e.g., public transportation management tools and integrated multi-modal traveler information) are paramount in the urban area. Urban environmental problems and crime problems also accentuate the need for services that address these problems. Note that these characteristics reflect those of a large urban area; small urban areas have different characteristics that must be considered, although they are not directly represented within the three specified scenarios.

The *rural scenario* is at the opposite end of the spectrum from the urban scenario. The rural scenario has fewer capacity-related problems, but many opportunities for driver misjudgment due to varied terrain and road conditions.

The rural traveler has unique safety and information needs that facilitate travel in these sparsely populated geographical areas, with broadly scattered services.

The *inter-urban scenario* can vary widely in its characteristics. Travel between Baltimore and Washington D.C., or Los Angeles and San Diego has a much different traffic flow pattern than that between Cedar Rapids and Minneapolis. The first two examples involve travel on highly-congested corridors, while the third example closely reflects attributes of the rural scenario for most of the route. The common features considered in characterizing the inter-urban scenario were high-speed, long-distance travel along major routes crossing jurisdictional boundaries, and supporting heavy commercial vehicle usage. Another attribute of the inter-urban scenario is the multi-modal transportation environment that includes inter-city bus, rail, and air services.

An analysis of the characteristics for each scenario yields goals, derived from the system goals, that are tailored to address scenario-specific needs. Table 3.1.2.1-2 presents a preliminary set of goals that focus on the needs of the urban, inter-urban, and rural scenarios. The table reflects special areas of emphasis within a scenario, rather than an absolute allocation of goals to each scenario. This interpretation is important, since many goals pertain to all scenarios. The areas of emphasis reflect special critical needs that may be prioritized through early deployment in a scenario.

Deployments that satisfy a "scenario-specific" goal will often benefit multiple scenarios as well. For example, deployment of a driver performance monitoring subsystem might have originally been initiated due to a critical run-off-the-road problem in rural and inter-urban areas, but benefits are also derived from this deployment when equipped vehicles are operated in urban areas.

Table 3.1.2.1-1. Scenario Characteristics

Urban Scenario

- High population density
- Large existing transportation and communications infrastructures
- Extensive arterial network, saturated at peak travel times
- Extensive freeway network, saturated and often congested
- Underutilized/non-optimized mass transit
- Heavy commuter traffic and Large latent demand
- Recurring and non-recurring congestion
- Extensive local pick-up/delivery activity
- Major terminus for goods shipping/receiving
- Air quality concerns
- More motor vehicle crashes
- High crime areas
- Limited land availability for additional facilities
- Multi-modal transportation

Inter-urban Scenario

- Mix of users (rural-based and urban-based users traveling through)
- Conditions vary widely from urban-like to rural
- Major interstate/state highway travel with secondary route alternatives
- Less emphasis on transit
- Intensive long-haul commercial vehicle usage
- Periodic congestion associated with holidays/weekends
- Non-recurring congestion due to incidents
- High-speed, long-distance travel
- Multi-jurisdictional
- Multi-modal transportation
- High single-vehicle accident rates
- Recreational travelers that demand traveler information services

Rural Scenario

- Mix of users (rural-based and urban-based users traveling through)
- Secondary roads with less frequent maintenance
- Steep grades/blind corners/curves/few passing lanes
- Large disparity in travel speeds (frequent passing)
- Long travel distances
- Fewer convenient detour options
- Adverse road surface and weather conditions
- Few navigational signs
- Less existing infrastructure
- Light usage/large geographical areas impede rapid emergency detection and response
- Lack of enforcement invites safety infractions/excess speed.
- More motor vehicle deaths
- Recreational travelers that demand traveler information services

Table 3.1.2.1-2. Identification of Scenario-Specific Goals

Goal	Scenario Emphasis		
	Urban	**Inter-Urban**	**Rural**

Increase operational efficiency and capacity of the transportation system	• Smooth traffic flow
	  • Signalized closed networks
	• Reduce delay associated with congestion
	  • Emphasis on system goals (saturated network)
	• Increase average vehicle occupancy
	• Increase capacity of existing facilities
	• Reduce time lost in intermodal interchange
		• Smooth traffic flow
		  • High volume thoroughfares
		• Reduce delay associated with congestion
		  • Emphasis on user goals (available capacity on alternate routes)
			• Reduce travel time
			  • Improve rural routing

Enhance personal mobility, convenience, and comfort of the transportation system	• Reduce travel time • Reduce congestion delay • Improve urban routing	• Increase intermodal interchange options • Increase trip end opportunities	• Increase trip end opportunities • Improve rural routing

Improve the safety of the Nation's transportation system	• Reduce accident frequency and severity
	  • rear-end
	  • highway-highway intersection
	  • highway-rail intersection
	  • secondary collisions
	  • truck overturns
	• Enhance traveler security
	• Reduce number of impaired drivers
		• Reduce accident frequency and severity
		  • rear-end
		  • secondary collisions
		  • truck overturns
		• Reduce number of impaired drivers
		  • Long trip fatigue
		• Improve EMS/roadway services responsiveness
			• Reduce accident frequency and severity
			  • run off the road
			  • rural intersection
			  • highway-rail intersection
			  • passing
			  • animals on road
			• Reduce safety impacts stemming from adverse road/weather conditions
			• Reduce number of impaired drivers
			  • Long trip fatigue
			• Improve EMS/roadway services responsiveness

Reduce energy consumption and environmental costs	• Reduce emissions/energy use associated with congestion
	  • Increase average vehicle occupancy
	  • Increase attractiveness of modal alternatives
	• Reduce need for new facilities
	• Effective incident management/routing
		• Reduce emissions/energy use associated with congestion
		• Effective incident management/routing
			• Reduce Vehicle Miles Traveled (VMT)
			  • Improve rural routing

Table 3.1.2.1-2. Identification of Scenario-Specific Goals (continued)

Goal	Scenario Emphasis		
	Urban	**Inter-Urban**	**Rural**

Enhance the present and future economic productivity of individuals, organizations and the economy as a whole	• Reduce travel time
	  • Reduce congestion delay
	  • Improve urban routing
		• Reduce costs incurred by fleet operators
		• Reduce cost of fee (toll) collection
		• Reduce travel time
		  • Reduce congestion delay
		  • Increase vehicle speeds
		• Reduce commercial vehicle regulation costs and delays
			• Reduce travel time
			  • Improve rural routing

Create an environment in which the development and deployment of ITS can flourish	• Apply technology to ITS architecture needs • Standardization and inter-operability to ensure marketable products • Industry participation to promote acceptance	• Apply technology to ITS architecture needs • Standardization and inter-operability to ensure marketable products • Industry participation to promote acceptance	• Apply technology to ITS architecture needs • Standardization and inter-operability to ensure marketable products • Industry participation to promote acceptance

3.1.2.2 Time Frame Specific Objectives

Just as the ITS will vary across scenarios, it will also change with time. Clearly the system will evolve, responsive to changing needs, availability of technologies, cumulative experience, and funding. To facilitate the analysis of this evolution, the view of the system at 5 ,10 and 20 year points from the start of the program have been selected. These correspond to the years 1997, 2002, and 2012.

Objectives which are specific to each of the 5, 10, and 20 year time frames have been derived from the system goals. Based on considerations of technological feasibility, market acceptance, and institutional issue resolution, these objectives condition the final evolutionary deployment. The overall time-sensitive objective is to first address those services that: 1) provide substantial benefit at relatively low cost, 2) present low technical and non-technical risk, and 3) form a foundation that can be effectively enhanced in future time frames. Table 3.1.2.2-1 characterizes time-phased objectives that show incremental deployment of increasingly sophisticated services at increasing levels of penetration.

Table 3.1.2.2-1: General Evolution of Implementation over Time

	Time Phase		
Category	**Early**	**Mid**	**Late**
Deployment (Transportation)			
Infrastructure	Freeways	Arterials	Streets and Roads
Vehicle	Buses, Trucks	High-end Autos	Automobiles
Capabilities			
Information	Uniform, Limited Personalized	Personalized	Fully Coordinated
Control	Warning/Advisory Systems	Partial Automation	Full Automation
Integration			
Systems	Individual subsystems	Integrated subsystems	Nationwide interoperability
Geographic	Jurisdiction	Regional	Area-wide

As presented in the table, the implementation evolves:

- Modally, starting with deployment in high value commercial and transit vehicles and moving to lower value private vehicles as the services become less expensive.

- Through the roadway hierarchy beginning with the most traveled routes and ending with the lightly traveled secondary streets and rural roads.

- Increasing user expectation as services become more sophisticated. Information services may progress from uniform broadcasts (everyone gets the same information) to interactive personalized services (subscribers receive information tailored to their specific needs) to system-wide coordinated services. Control services begin by supplying advice and warnings which do not dilute user control. As technology improves, institutional issues are resolved, and user confidence is increased, more control responsibility can be automated. Where appropriate, fully automated systems may be realized.

- In the degree of integration as independent products are installed on a limited basis and then integrated and expanded to service broad geographic regions.

Table 3.1.2.2-2 presents a set of specific objectives for the three time frames which address five of the six system goals. The list of time-sequenced objectives will expand and mature over the course of the ITS architecture development as deployment issues are further analyzed.

Table 3.1.2.2-2: Representative Objectives by Time Frame

Goal	Time Frame Emphasis		
	5 Years	**10 Years**	**20 Years**

Increase operational efficiency and capacity of the transportation system	• Make current data available to travelers
	  • Congestion
	  • Static routing
	  • Transit information
	  • Ride share information
	• Improve incident response
	• Improve traffic management
	• Prioritize transit right-of-way
	• Improve transit management
	• HOV implementation
		• Coordination between traffic and transit management
		• Enhanced paratransit
		• Real-time ride share
		• HOV pricing incentives
		• Real-time route guidance (user goals)
			• Real-time route guidance (system goals)
			• Congestion pricing
			• User-responsive public transportation
			• Fully automated control to increase capacity

Enhance personal mobility and the convenience and comfort of the transportation system	• Mobility
	  • Increase personal travel opportunities
	  • Decrease personal costs of travel including:
	    • Increase awareness, and ease of use of transit and ridesharing
	    • Travel time
	    • Travel time reliability
	    • Travel cost
	    • Comfort, stress, fatigue, and confusion
	    • Safety and personal security
	  • Increase sense of control over one's own life from predictable system operation
	  • Decrease cost of freight movement to shippers, including:
	    • More reliable "just-in-time" delivery
	    • Travel time
	    • Travel cost
	    • Driver fatigue and stress
	    • Cargo security
	    • Safety (e.g., from tracking hazardous material)
	    • Transaction costs
		• Economic Development
		  • Increase access to:
		    • Labor
		    • Materials
		    • Markets
		  • Increase industrial output
		  • Reduce costs
		  • Increase investment in plant and equipment
		  • Opportunities for new services/product innovation
		  • Opportunities for public/private partnerships
		  • Increase international competitiveness
			• Personal Adaptations
			  • Lifestyle changes
			  • Land use (settlement) pattern changes

Table 3.1.2.2-2: Representative Objectives by Time Frame (continued)

Goal	Time Frame Emphasis		
	5 Years	**10 Years**	**20 Years**

Improve the safety of the Nation's transportation system	• Provide driver warnings in unsafe/safe circumstances
	  • buses
	  • trucks
	• Make current data available to travelers
	  • weather/road conditions
	  • incidents
	• Improve notification times in collisions
	  • buses
	  • HAZMAT
	• Automated HAZMAT tracking
	• Improve real-time vehicle diagnostics
	• Personal travel security
	• Mayday signaling to improve safety
	• Driver warnings of unsafe conditions via infrastructure devices
	• Improve HRI Signage consistency/understanding
		• Assume partial control in unsafe/safe circumstances
		  • buses
		  • trucks
		• Driver monitoring
		  • buses
		  • trucks
		• Provide driver warnings in unsafe circumstances
		  • autos
		• Automated collision notification
		• Advanced HRI warning systems/barriers
			• Fully automated control in unsafe/safe conditions
			  • buses
			  • trucks
			  • autos
			• Driver monitoring
			  • autos
			• Smart intersections
			  • Highway-Highway
			  • Highway-Rail

Reduce energy consumption and environmental costs	• Reduce vehicle emissions due to congestion • Reduce noise pollution • Reduce neighborhood traffic intrusiveness • Reduce fuel consumption due to congestion		
Enhance the present and future economic productivity of individuals, organizations and the economy as a whole	• Improve fleet management • Automate toll collection • Streamline national commercial vehicle regulation	• Streamline multi-national commercial vehicle regulation	• Automated vehicle operation

3.2 Conceptual Approach

ITS user services are implemented through the identification of user requirements. The user requirements are met through transportation and communication elements. The transportation element enables the movement of people and goods, while the communication element provides all necessary information transfers. The ITS architecture is intended to provide a framework for the interacting portions of these elements to facilitate standardization, efficiency, and synergy in user service implementation.

3.2.1 User Service Support

Thirty "user services" have been defined to date to meet the broad ITS goals. These have been bundled into seven broad categories as shown in Table 3.2-1.

These multiple user services will be deployed in different circumstances to meet many different kinds of needs for a wide variety of different customers. A main consideration to the architecture development approach is the variation in user service capabilities. There will be significant differences in the degree that each of the 30 user services is evolved and integrated, based on time frame and jurisdictional constraints. No one location will implement all 30 user services to the highest level of functionality and integration possible.

The successful architecture will be one that has the desired variations in user service functionality, and are recognized and reflected in the functional decomposition of the system requirements. Table 3.2-1 provides a sampling of the variations in user service implementations that may be desirable as the system is deployed across the nation over time. The functional variations reflect both increasing levels of capability from left to right and operation in different scenarios and applications.

The variations presented in the table will be accommodated in the architecture by: 1) performing the functional decomposition to a sufficient level of granularity so that "optional" functions are separable and distinct, 2) developing the primary functional relationships so that optional functions are not required for operation of the remainder of the system, and 3) developing the physical architecture that identifies the range of capability that is to be provided by each of the components. This approach helps to ensure that the architecture will support the desired adaptability and flexibility for incremental deployment in varied scenarios.

Table 3.2-1. Sample Variations in User Service Capabilities

User Service	Deployment Variations		
	Variation 1	**Variation 2**	**Variation 3**
Travel and Transportation Management			
En Route Driver Information	General in-vehicle display of static sign information along with driver advisories for current congestion, incident, conditions, etc.	Sign information tailored to current conditions and driver advisory information filtered/tailored to meet driver's specific needs	Sign information tailored to vehicle and current conditions along with predictive driver advisories integrated with route guidance service.
Route Guidance	Autonomous route guidance supplying static directions	Real-time route guidance based on current conditions.	Coordinated real-time route guidance to achieve network-wide optimizations
Traveler Services Information	Fixed "Yellow pages" service optimized for traveler queries.	Mobile service providing information based on location/need (e.g. gas stations in range)	Integrated electronic reservation/payment service
Traffic Control	Enhanced freeway control	Enhanced network control	Integrated area-wide control
Incident Management	Automated incident detection. May rely on traffic monitoring, direct reports, or both	Automated detection, verification, response plan recommended to operator	Complete incident management automation. Minimal man-in-loop operator control.
Emissions Testing and Mitigation	Roadside pollution assessment.	Area-wide pollution monitoring.	Integrated area-wide air quality strategies.
Highway-Rail Intersection	Standard traffic control devices at Highway-Rail Intersections	Coordination with railroads to enhance traffic management	Immobile vehicle detection and emergency notification
Travel Demand Management			
Demand Management Operations	Demand monitoring and public awareness information	HOV and parking facility administration	Dynamic user fee based on time, route, number of passengers, emissions, etc.
Pre-Trip Travel Information	Real-time information available to travelers at home, office, etc.	Integrated data for all modes available in one repository	Route, time, and mode recommendations made
Ride Matching and Reservation	Match private vehicle owners/ operators with potential riders	Include commercial transit providers as match options	Include support for ride share financial transactions.
Public Transportation Operations			
Public Transportation Management	Centralized schedule monitoring and management	Add off-line analysis/ planning and personnel management support	Integrate with traffic control to enhance real-time schedule adherence capability
En Route Transit Information	Current route/schedule information available. Limited interaction.	Integrated multi-modal information with decision support	Integrated with electronic payment service (ticket/fare card purchase)
Personalized Public Transit	Reservation-based rider request capability.	Vehicle assignment with optimized vehicle schedules.	Real-time vehicle assignment.
Public Travel Security	Physical security, surveillance, screening, and alarm systems	Driver/traveler initiated silent alarm (vehicle-based)	Alarm capability integrated with personal communications services.

Table 3.2-1. Sample Variations in User Service Capabilities (continued)

User Service	**Deployment Variations**		
	Variation 1	**Variation 2**	**Variation 3**
Electronic Payment			
Electronic Payment Services	Electronic toll collection	Electronic fare collection/ Electronic parking payment.	Integrated electronic payment service supporting all modes.
Commercial Vehicle Operations			
Commercial Vehicle Electronic Clearance	Use historical data and WIM to preclear carriers with annual registration.	Extended service which preclears those with temporary permits	Vehicle and driver condition automatically monitored and considered in preclearance.
Automated Roadside Safety Inspections	On-line access to historical safety records for identified vehicles	Vehicle-based diagnostics collected and monitored	Driver status and condition monitored and considered
On-Board Safety Monitoring	Safety monitoring with automated driver notification	Extended to supply notification to carrier	Extended to supply notification to enforcement agencies
Commercial Vehicle Administrative Process	Electronic purchase of annual credentials from base state	Add purchase of temporary credentials/permits from other states.	Automated mileage and fuel reporting
Hazardous Material Incident Response	Enforcement and HAZMAT response teams provided with cargo information.	Operational focal point to coordinate with other agencies.	Real-time HAZMAT incident response coordination.
Freight Mobility	Fleet location and status monitoring	Integrated route guidance	Specific specialized fleet capabilities
Emergency Management			
Emergency Notification and Personal Security	Motorist initiated distress signal	Automated distress signal initiated by vehicle collision	Content added to message for special uses (e.g. HAZMAT)
Emergency Vehicle Management	Vehicle dispatch support	Route guidance directing driver to the scene	Integration with traffic control to optimize travel times.
Advanced Vehicle Controls and Safety Systems			
Longitudinal Collision Avoidance	Driver warning of potential longitudinal collisions	Temporary partial control in collision avoidance situation	Full control, integration with lateral control service
Lateral Collision Avoidance	Blind spot warning and/or partial control	Lane holding warning and/or partial control	Full control, integration with longitudinal control service
Intersection Collision Avoidance	Signalized intersection violation (e.g. run red light) detection and control override	Potential intersection collision warning/partial control	Fully automated intersection control
Vision Enhancement for Crash Avoidance	Independent vision enhancement service	Integrated with in-vehicle signing/other collision avoidance services	
Safety Readiness	Enhanced vehicle condition monitoring	Unsafe road conditions monitoring	Impaired driver monitoring and control override
Pre-Crash Restraint Deployment	Sensor-based detection and restraint deployment	Vehicle to vehicle coordination and restraint deployment	Personalized restraint based on occupant characteristics

Table 3.2-1. Sample Variations in User Service Capabilities (continued)

User Service	Deployment Variations		
	Variation 1	Variation 2	Variation 3
Automated Highway System	In-vehicle collision-avoidance precursors to AHS	Minimum roadside intelligence	Fully automated vehicle operations

The user service variations will be incrementally deployed over time within the different scenarios. Table 3.2-2 presents a preliminary allocation of user service capabilities to scenario and time frame. For purposes of interpreting the table, a user service is considered "fully deployed" when it's full capabilities are commercially available for implementation nationwide. In addition, these capabilities are in operational use (not a limited operational test) in at least one location in the country.

As depicted in the table, partial user service capabilities are first deployed followed by more mature and capable versions until the "full deployment" state is reached. The particular subset of capabilities that are deployed early will vary, depending upon the particular needs and preferences of the local jurisdiction. During evolutionary deployment analysis, these user service variations will be considered further, along with their relationship to each of the scenario/time frame combinations.

3.2.2 Architecture Approaches to Meet Objectives

In addition to supporting user services, the architecture must be able to accommodate and provide planning support to achieve the full range of architecture development objectives. Approaches have been identified that will result in an architecture that satisfies each of these objectives. To achieve the envisioned benefits, the successful ITS architecture must possess the following attributes and be implemented in the following manner:

1. The architecture must accomodate modular designs. The user service functionality must be distributed across modular subsystems to enhance reliability, achieve scalability, and satisfy differing needs. Flexibility in distribution of the functionality within the infrastructure must be allowed to enable a range of centralized and distributed processing options. Different options may be attractive for different scenarios and time frames, but no option should be excluded arbitrarily or through oversight.

2. The interface to the mobile user must be standardized to achieve a seamless, national ITS. Clear allocation of functionality between the infrastructure and mobile subsystems will be specified, along with the range of communications options necessary to implement related ITS services.

3. The architecture must facilitate the sharing of data across subsystems. Data availability is guaranteed by the architecture through identification of database services functionality, which supports data sharing in a manner transparent to the using application. Specific architectural features that enable data interchange are critical for supporting unforeseen future user services.

4. The architecture must allow for flexibility in system designs and operations in order to accommodate jurisdictional preferences. For example, the architecture may support both centralized and distributed traffic control strategies to accommodate differing preferences and existing infrastructures. The choice can be preserved by identifying the required functions and interfaces in an allocation-independent (logical) manner. Alternative partitioning can be used to identify two alternative physical descriptions, and two standard information routing and interface alternatives. This technique will be used to develop the architecture whenever multiple partitioning alternatives exist and have merit.

5. The architecture that is implemented will build upon the existing infrastructure, while providing an upgrade path to accommodate technological advances. To support the resulting multiplicity of implementations with a single architecture, subsystems must be defined in an implementation-independent manner and structured to present a general-purpose interface to the remainder of the system. This application of the well-known

"black box" principle must be applied throughout the architecture definition process. This strategy minimizes the architecture's sensitivity to technological variability and evolution.

6. The architecture will be structured to support a wide range of communications medium and protocol implementations. The architecture will include communication interface subsystem(s) that will isolate the communications implementation from the remainder of the architecture. This approach groups all communications-dependent functionality and does the following: 1) improves initial flexibility, since a range of interface subsystems can be identified to meet individual needs, and 2) minimizes the impact of modifying or upgrading a communications system that supports the architecture.

3.3 User Identification

In the previous section, the ITS architecture was defined as a set of transportation and communications elements working together to provide services to the end user. To capture the influence of institutional issues on the architecture, a third institutional element may be identified. The relationship of the institutional, transportation, and communication elements can be represented as shown in Figure 3.3-1. Each element includes a distinct subset of the people, capabilities, and constraints associated with individual ITS user services. These architecture elements together provide the required user services and satisfy the ITS goals and objectives.

Seven groupings of the ITS users have been identified and categorized by the DOT as listed in Table 3.3-1.

In the following sections, the architecture elements are discussed and more fully defined from the perspective of user identification. ITS service developers, operators, maintainers, and users associated with each of the three elements are identified.

Table 3.2-2: User Service Scenario and Time Frame Emphasis

User Service	Scenario			Time Frame		
	Urban	Inter-Urban	Rural	5	10	20
Travel and Transportation Management						
En Route Driver Information	✓	✓	✓	○	○	●
Route Guidance	✓	✓	✓	•	○	●
Traveler Services Information	✓	✓	✓	•	○	●
Traffic Control	✓	✓		○	●	
Incident Management	✓	✓		○	●	
Emissions Testing and Mitigation	✓	✓		•	○	●
Highway-Rail Intersection	✓	✓	✓	•	○	●
Travel Demand Management						
Demand Management and Operations	✓	✓		•	○	●
Pre-Trip Travel Information	✓	✓	✓	○	●	
Ride Matching and Reservation	✓			○	●	
Public Transportation Operations						
Public Transportation Management	✓			●		
En Route Transit Information	✓	✓		○	●	
Personalized Public Transit	✓	✓		○	●	
Public Travel Security	✓			•	○	●
Electronic Payment						
Electronic Payment Services	✓	✓		○	●	
Commercial Vehicle Operations						
Commercial Vehicle Electronic Clearance		✓		●		
Automated Roadside Safety Inspections		✓		○	●	
Commercial Vehicle Administrative Processing	✓	✓	✓	●		
On-Board Safety Monitoring	✓	✓	✓	○	●	
Hazardous Material Incident Response	✓	✓	✓	○	●	
Freight Mobility	✓	✓	✓	●		
Emergency Management						
Emergency Notification and Personal Security	✓	✓	✓	○	●	
Emergency Vehicle Management	✓	✓	✓	○	●	
Advanced Vehicle Control and Safety Systems						
Longitudinal Collision Avoidance	✓	✓	✓	•	○	●
Lateral Collision Avoidance	✓	✓	✓	•	○	○
Intersection Collision Avoidance	✓	✓	✓		•	○
Vision Enhancement for Crash Avoidance		✓	✓		•	○
Safety Readiness	✓	✓	✓	•	○	●
Pre-Crash Restraint Deployment	✓	✓	✓		•	○
Automated Highway System	✓	✓				•

✓: Indicates need for service by scenario. Service likely to be deployed at a full level of service in the scenario.
• : Preliminary deployment of a subset of user service capabilities
○: Partial deployment of subset capabilities/preliminary deployment of full service capabilities
●: Deployment of full service capabilities

3.3.1 Institutional Element

The Institutional element highlights issues related to ITS that must be addressed by the architecture. The Institutional element reflects the jurisdictional boundaries (municipality, county, state, and federal government agencies) and organizational boundaries within jurisdictions, and includes private companies and public-private ventures. It is in this element that funding is acquired for user services that are implemented. Each jurisdiction and organization will determine the services to provide and the cost. Private companies will provide services that may bridge across jurisdictional boundaries as influenced by market forces. The ITS architecture must accommodate each of these political divisions and scenario variations, and conform within the legal and economic constraints associated with this element.

Table 3.3-1. ITS System Users.

Group	Users
Transportation Infrastructure Providers	State Agencies
	MPOs/Regional Agencies
	City Agencies
	County Agencies
	Toll Authorities
Consumers	Commuters
	Emergency Response Users
	Business Users
	Leisure Users
	Special Needs Travelers (Disabled, Elderly, etc.)
Freight Operations	Trucking Companies
	Air Freight
	Railroads
	Shippers
	Regulators
	Port Authorities
Passenger Operations	Transit Agencies
	Ridesharing Private Fleet Operators (Taxis, etc.)
Public Safety Services	Emergency Managers
	Police Agencies
	Fire Agencies
	Emergency Medical Services
	Towing Operators
	HAZMAT
Product/Service Providers	Vehicle Manufacturers
	Maintenance Forces
	Communications and Information Technology Products
	System Integrators and Consultants
	Construction
	Businesses Serving People on the Move (Retail, Advertising, etc.)
Policy/Interest Groups	Federal Agencies
	Local and State Agencies (includiing Planning Agencies)
	Academia
	Associations/Societies
	Special Interests (Environmental, Safety, etc.)

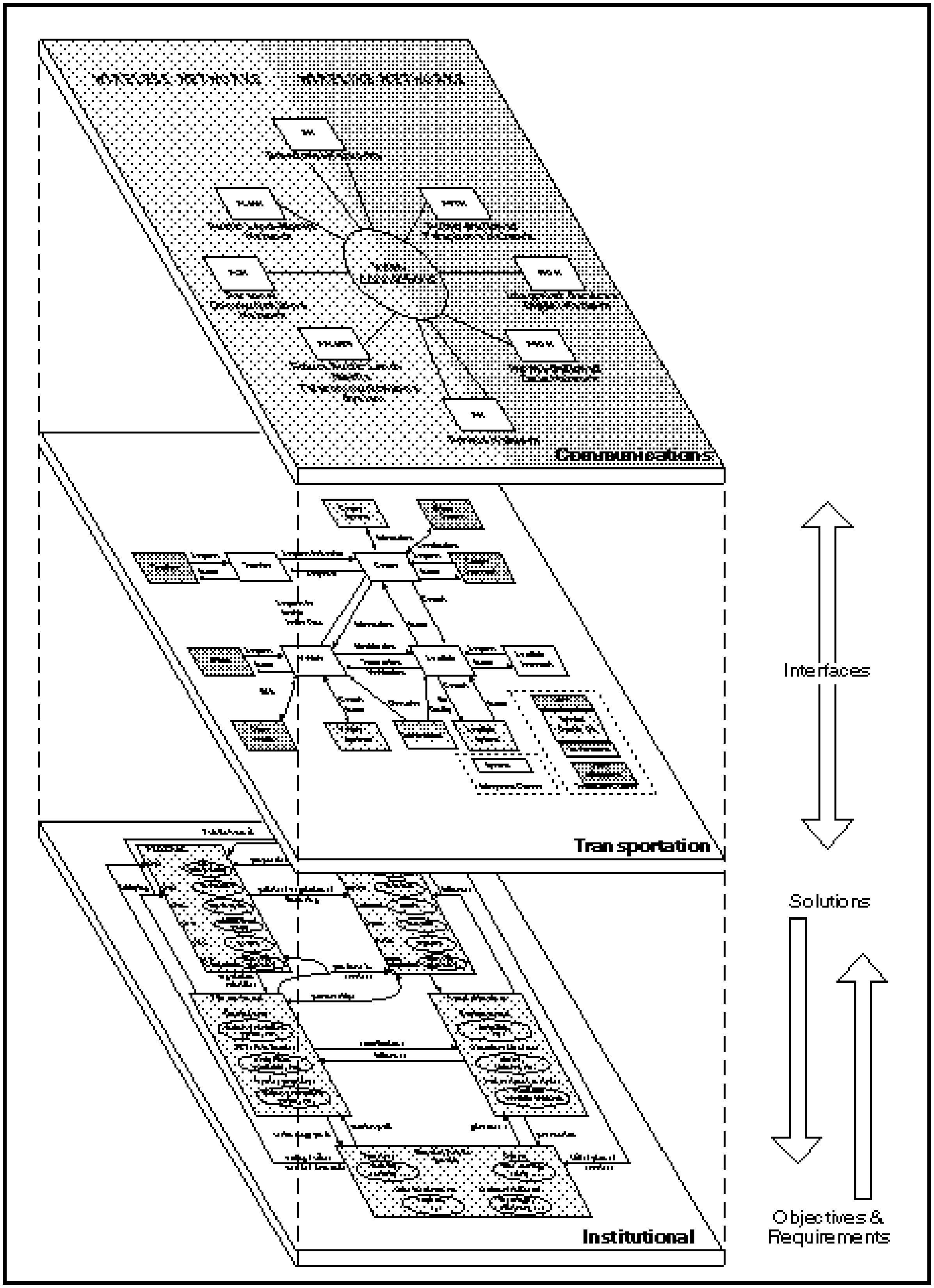

Figure 3.3-1: Multi-Layered ITS Architecture Concept

3.3.2 Transportation Element

The transportation infrastructure includes roadways, vehicles, traffic management centers, ports of entry, traveler information providers, fleet management centers, emergency services facilities, and transit facilities. These entities are treated as distributed nodes within the transportation element, without regard to physical communications connectivity (which is modeled in the communications element below).

The transportation element will include advanced technologies to provide services that are more convenient and less expensive for the fleet manager and private user. New control systems will allow increased automation, and provide transit buses, automobiles, and trucks with affordable guidance, communications, navigation, and safety equipment. Advanced transportation management functions will enable public and private operating user agencies (city and state traffic engineers, transit operators, railroads, and large fleet operators) to coordinate their various subsystems and achieve maximum use of transportation modes and facilities.

Two distinct types of users are associated with this element: 1) transportation professionals who select, operate, and maintain the transportation equipment, and 2) the public at large that uses surface transportation. Transportation professionals include city and state traffic engineers, traffic operations personnel, field maintenance personnel, construction and maintenance personnel, emergency dispatchers, fleet managers, pick-up/delivery drivers, professional drivers, commercial vehicle owners/operators, fixed route transit operators, paratransit operators, toll operators, customs officers, inspectors, and emergency services personnel. Third party service providers include traveler information providers, map database and/or Geographic Information System (GIS) providers, and system integrators. The infusion of technology into the transportation sector will likely create requirements for additional specialists. The surface transportation user is the public at large and includes pedestrians, bicyclists, motorcyclists, drivers, car poolers, and transit users. These users reflect the diversity of the population as a whole; special needs (e.g., the economically disadvantaged, the elderly, and the disabled) must be accommodated to benefit the broadest cross section of the population.

3.3.3 Communications Element

The communications infrastructure is critical to the success of the ITS architecture. It provides the transfer of information among different transportation entities using an air interface, mobile transceivers, base stations, switches, wireline media, etc. Penetration and usage will depend on the cost of communication equipment, the infrastructure, and service. The level of penetration and degree of usage will, in turn, impact the achieved benefit. These benefits and costs are also a function of who will build, operate, and maintain the communication element. The potential development paths include: 1) capitalizing on the private sector’s general-purpose telecommunications investment, 2) developing a new dedicated system with private sector funds, and 3) creating a new infrastructure with public funds, or via a public-private cooperative venture.

The ITS architecture will be oriented towards capitalizing on the existing and emerging general-purpose communications infrastructure to reduce cost and risk. The private sector has built and operated an expansive communication infrastructure that can be leveraged to support a significant number of ITS user services. As demand grows and new applications are introduced, this infrastructure will evolve and continue to expand. Using this approach, the financial responsibility associated with deployment is assumed by the company operating a particular network .

The communications element includes a number of service providers that should be included in the list of ITS users. Communication service providers include those who deploy, manage, and maintain communications networks, those who run the billing and clearinghouse functions associated with electronic payment services. Also included are communications equipment manufacturers and individual commercial communications users who employ the basic communications service to provide value-added information services.

3.3.4 User Service Developers, Operators, and Users

Table 3.3.4-1 presents the results of an analysis that identifies the users for each of the user services. First, the table presents a rough qualitative measure of the relative public benefit and private benefit (market potential) for each service. Based on these measures, the table next identifies the likely influence of the private and public sectors in the funding and development of each of the services. A high public benefit normally indicates public sector involvement in the service, even if market potential is relatively low. Conversely, services that have high private benefit potential but provide lesser benefit to the general public are candidates for private funding, development, and operation. Finally, the table identifies the system operators and system users associated with each service.

Note that the information in this table presents a reasonable starting point, rather than an absolute identification of funding sources and user roles for each service. Detailed analysis of these issues will be provided as the architecture and its deployment is further defined. Additional factors that will be addressed are as follows:

1. Market potential has a time dimension that must be considered in evaluating likely private sector participation.

2. Each of the user services include many functions; these functions should be individually considered and allocated to provide a higher resolution definition of who funds, who builds, and who operates a particular service.

3. The question of "who funds, who builds, and who operates" may differ across jurisdictions, and initiate many creative alternatives such as public-private partnerships, entry by private companies into operation of transportation segments which have traditionally been publicly administered, and public subsidizing/incentivizing of private efforts which achieve public benefit. These, and other creative alternatives, must be considered.

3.4. System Interactions

The identified user services interact with each other and the outside world to varying degrees. An analysis of Table 3.3.4-1 indicates a natural grouping of tightly coupled services (travel planning, traveler information, travel management, travel payment, commercial vehicle operations, advanced vehicle safety systems, and emergency management); the groups themselves are weakly interconnected. Although the ITS architecture is viewed as a whole during development of the logical architecture, this interconnectivity pattern hints that the resulting logical architecture will ultimately consist of loosely coupled subarchitectures.

User service inter-relationships and the system's interactions with the outside world will be further analyzed during logical architecture development. The user interacts with ITS to receive user services both directly and indirectly through the choices the user makes.

3.4.1 Direct Interactions

The users identified in section 3.3 who directly interact with the system fall into two basic categories: 1) system users (e.g., commuters and business users), and 2) system operators (e.g., private fleet operators). Both system users and operators interact with the system by making requests for ITS services. The architecture provides responses to the user requests and also provides unsolicited notifications of anomalies and general system status. Commuters also interact with the system through control of their vehicles. These vehicle control inputs are monitored and augmented by many of the automated vehicle control services. In turn, the commuters are "controlled" by the architecture services indirectly, through services that influence route selection and control right-of-way.

3.4.2 Indirect Interactions

Each system user performs a personal cost-benefit analysis when asking the question "Is this feature or service worth the cost?" This is done for each component of the system, which forces the architects to ask the same question for each system component as it is deployed over time at different locations.

These user choices have two types of implications:

1. Users may buy in to a basic system, but at some point find that the incremental benefits provided by an upgraded service are not worth the incremental cost and fail to support further enhancements.

2. There may be a minimum set of features below which potential users are not interested in the system at the anticipated cost. This may require rapid deployment of several connected services to achieve a core feature set and an acceptable level of user participation.

The system operator has the same type of indirect interaction with ITS services for which the operator is the primary "user". Preference for certain types of equipment and a substantial investment in existing equipment may affect acceptance of fresh approaches or new technologies. The architecture must consider and support when possible this bias, while maintaining upward compatibility with evolving transportation system technologies and designs.

Table 3.3.4-1. ITS Funding Sources, Developers, Operators, and Users

User Service	Public Benefit	Private Benefit	Who Funds	Who Builds	Who Operates	Who Uses
Travel and Transportation Management						
En Route Driver Information	High	High	Infrastructure Public Vehicle Private	Infrastructure Public/Private Vehicle Private	Public/ Private	commuters, business users, leisure users, special needs travelers, trucking companies, shippers, private fleet operators, transit agencies, emergency managers, police agencies, fire agencies, emergency medical services, towing operators, HAZMAT, businesses serving people on the move
Route Guidance	Moderate	High	Infrastructure Public Vehicle Private	Infrastructure Public/Private Vehicle Private	Public/ Private	commuters, business users, leisure users, special needs travelers, trucking companies, shippers, private fleet operators, transit agencies, emergency managers, police agencies, fire agencies, emergency medical services, towing operators, HAZMAT, businesses serving people on the move
Traveler Services Information	Moderate	High	Private	Private	Private	commuters, business users, leisure users, special needs travelers, trucking companies, shippers, private fleet operators, system integrators and consultants, construction, businesses serving people on the move

Table 3.3.4-1. ITS Funding Sources, Developers, Operators, and Users (continued)

User Service	Public Benefit	Private Benefit	Who Funds	Who Builds	Who Operates	Who Uses
Traffic Control	High	Moderate	Public	Public/ Private	Public	federal agencies, state agencies, MPOs/regional agencies, city agencies, county agencies, emergency managers, police agencies, fire agencies, emergency medical services, HAZMAT, construction, transit agencies, system integrators and consultants, construction
Incident Management	High	Moderate	Public	Public/ Private	Public	federal agencies, state agencies, MPOs/regional agencies, city agencies, county agencies, emergency managers, police agencies, fire agencies, emergency medical services, HAZMAT, businesses serving people on the move
Emissions Testing and Mitigation	High	Moderate	Public	Public	Public	federal agencies, state agencies, MPOs/regional agencies, city agencies, county agencies, toll authorities, transit agencies, police agencies
Highway-Rail Intersection	High	High	Private/ Public	Infrastructure Private/Public Vehicle Private	Infrastructure Private/Public Vehicle Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, railroads, shippers, vehicle manufactures, communications and information technology products, federal agencies, academia, special interests
Travel Demand Management						

Table 3.3.4-1. ITS Funding Sources, Developers, Operators, and Users (continued)

User Service	Public Benefit	Private Benefit	Who Funds	Who Builds	Who Operates	Who Uses
Demand Management and Operations	High	Moderate	Public	Public/ Private	Public	federal agencies, state agencies, MPOs/regional agencies, city agencies, county agencies, toll authorities, transit agencies
Pre-Trip Travel Information	Moderate	High	Public/Private	Private	Private	commuters, business users, leisure users, special needs travelers, trucking companies, shippers, private fleet operators, transit agencies, emergency managers, police agencies, fire agencies, emergency medical services, towing operators, HAZMAT, businesses serving people on the move
Ride Matching and Reservation	High	Moderate	Public	Private	Public	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, private fleet operators
Public Transportation Operations						
Public Transportation Management	High	Moderate	Public	Private	Public	transit agencies
En Route Transit Information	High	Moderate	Public	Public/ Private	Public	commuters, business users, leisure users, special needs travelers, transit agencies, businesses serving people on the move
Personalized Public Transit	High	Moderate	Public	Private	Public	transit agencies
Public Travel Security	High	High	Infrastructure Public Mobile Private	Private	Public	transit agencies, commuter, business users, leisure users, special needs travelers, police agencies, towing operators
Electronic Payment						

Table 3.3.4-1. ITS Funding Sources, Developers, Operators, and Users (continued)

User Service	Public Benefit	Private Benefit	Who Funds	Who Builds	Who Operates	Who Uses
Electronic Payment Services	Moderate	High	Private	Private	Public/ Private	toll authority, transit agencies,
Commercial Vehicle Operations						
Commercial Vehicle Electronic Clearance	Moderate	High	Infrastructure Public Vehicle Private	Private	Public	regulators, shippers, trucking companies
Automated Roadside Safety Inspections	High	Moderate	Infrastructure Public Vehicle Private	Private	Public	regulators, trucking companies, shippers
Commercial Vehicle Administrative Processes	Low	High	Infrastructure Public Vehicle Private	Private	Public	trucking companies, railroads, shippers, port authorities,, regulators
On-Board Safety Monitoring	High	High	Private	Private	Private	trucking companies, regulators
Hazardous Material Incident Response	High	High	Public	Public	Public	HAZMAT, police agencies, fire agencies, emergency managers, emergency medical services, trucking companies
Freight Mobility	Low	High	Private	Private	Private	trucking companies, railroads, shippers. towing operators
Emergency Management						
Emergency Notification and Personal Security	Moderate	High	Private	Private	Private	HAZMAT, police agencies, fire agencies, emergency managers, emergency medical services
Emergency Vehicle Management	High	High	Public	Private	Public	emergency managers, police agencies, fire agencies, emergency medical services, towing operations, HAZMAT

Table 3.3.4-1. ITS Funding Sources, Developers, Operators, and Users (continued)

User Service **Advanced Vehicle Control and Safety Systems**	Public Benefit	Private Benefit	Who Funds	Who Builds	Who Operates	Who Uses
Longitudinal Collision Avoidance	High	High	Private/ Public	Private	Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, shippers, vehicle manufacturers, communications and information technology products, federal agencies, academia, special interests
Lateral Collision Avoidance	High	High	Private/ Public	Private	<u>Infrastructure</u> Public <u>Vehicle</u> Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, shippers, vehicle manufacturers, communications and information technology products, federal agencies, academia, special interests
Intersection Collision Avoidance	High	High	Private/ Public	<u>Infrastructure</u> Public/Private <u>Vehicle</u> Private	<u>Infrastructure</u> Public <u>Vehicle</u> Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, shippers, vehicle manufacturers, communications and information technology products, federal agencies, academia, special interests

Table 3.3.4-1. ITS Funding Sources, Developers, Operators, and Users (continued)

User Service	Public Benefit	Private Benefit	Who Funds	Who Builds	Who Operates	Who Uses
Vision Enhancement for Crash Avoidance	High	High	Private/ Public	Private	Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, shippers, vehicle manufacturers, communications and information technology products, federal agencies, academia, special interests
Safety readiness	High	High	Private/ Public	Private	Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, shippers, vehicle manufacturers, communications and information technology products, federal agencies, academia, special interests
Pre-Crash Restraint Deployment	High	High	Private/ Public	Infrastructure Public/Private Vehicle Private	Infrastructure Private Vehicle Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, shippers, vehicle manufacturers, communications and information technology products, federal agencies, academia, special interests

Table 3.3.4-1. ITS Funding Sources, Developers, Operators, and Users (continued)

User Service	Public Benefit	Private Benefit	Who Funds	Who Builds	Who Operates	Who Uses
Automated Highway System	High	High	Private/ Public	Private/ Public	Infrastructure Public Vehicle Private	commuters, business users, leisure users, special needs travelers, transit agencies, trucking companies, shippers, vehicle manufacturers, communications and information technology products, federal agencies, academia, special interests, system integrators and consultants, construction, associations/societies

4.0 OPERATIONAL REQUIREMENTS

Operational requirements define the system processes, information flows, performance parameters, and technical and non-technical constraints which the ITS must incorporate, be developed from, and operationally satisfy. These requirements specify an initial system-level basis from which development of an ITS architecture can take place.

Operational requirements are primarily developed from requirements analyses conducted on user service and program information obtained from the *User Service Requirements,* dated July 4, 1994 (Attachment 6, to the USDOT IVHS Phase II Architecture Development program, contract no. DTFH61-95-C-00067, dated February 1, 1995), and the *National ITS Program Plan*, dated March, 1995. Other source data include information gathered from transportation-related documents; such as, Department of Transportation's IVHS Strategic Plan Report to Congress, dated December 18, 1992; *Advanced Transportation Systems Program Plan, Draft Caltrans New Technology and Research Program, dated January 9, 1995*; and other technology development and early deployment programs.

Operational requirements are organized into system-level requirements, user requirements, performance requirements, and program requirements.

4.1 System-level Requirements

The ITS architecture, hereinafter referred to as the "system", shall provide the operational framework whereby currently-identified user services can be configured and seamlessly integrated to provide reliable, accurate, and timely travel information and services for users of transportation facilities. In order to provide this framework, the system must meet a number of constraints:

- Accommodate a phased implementation to take advantage of technological/societal changes over the next 20 years.
- Integrate with the existing infrastructure.
- Account for the existing political infrastructure.
- Allow for distributed authority.
- Account for vested interest groups.
- Incorporate the existing commercial vehicle operating procedures.
- Use a mixture of private and government funding.
- Allow for a mixture of public, private, and commercial ownership.

These constraints lead to a series of high-level requirements for the ITS architecture. These requirements are derived through analysis including the experience of transportation experts and architecture development team members. Adopted as principles to guide the architecture development process, these principles should do the following:

- Provide flexible control.
- Leverage existing infrastructure.
- Offer incremental levels of system (services).
- Provide a highly modular system.
- Utilize detailed, open standardization to maximize interoperability, reduce market entry risk.
- Provide an easy upgrade path for future technology insertion.
- Facilitate information exchange.
- Provide wireless encryption and database access control requirements.
- Require vehicle-to-roadside communication common interfaces for vehicles.
- Emphasize in-vehicle equipment and safety.
- Build upon existing institutional arrangements.
- Offer a wide variety of choices to assure equity, avoid new public liabilities, and facilitate private industry profitability.
- Balance number of choices with manageability and marketable differences.
- Focus on user acceptance.

Formally, these system-level requirements are described by paragraphs 4.1.1 through 4.1.8.

4.1.1 Service Availability and Quality

The system shall provide the framework for user services that can be configured, implemented, and integrated to provide reliable, accurate, and seamless user/service information delivery, and exchanges in a timely, cost-effective manner. The system shall provide a consistent level of high service quality between service providers, geographic locations, or system configurations where compatible.

4.1.2 Service Interoperability

The system shall provide the framework and integration necessary for service interoperability between user services within a native service provider, or between different service providers.

4.1.3 Service Continuity

The system shall provide the framework and integration necessary for service continuity between service providers offering the same or similar services.

4.1.4 Service Information Management and Distribution

The system shall support user service information collection, processing, management, coordination (i.e., sharing), and distribution across multiple transportation (user) services. The system shall provide for information access control, updates, protection, and distribution for those services that utilize information processing systems.

4.1.5 Service Growth, Flexibility, and Expansion

The system shall support growth, flexibility, and expansion of user services and interactions with external, non-ITS service elements. The system shall provide the capability to accommodate or incorporate existing technology and infrastructures for currently-identified user services, future ITS user services, and any interactions with external, non-ITS services. The system shall also provide a comparable level of integration, operational continuity, and performance.

4.1.6 Equity of Service and Support

The system shall provide an equitable distribution of costs and benefits among service providers, a wide demographic segment of society (i.e., elderly, disabled, financially disadvantaged, etc.), and geographic regions (i.e., urban, interurban, rural, warm, or cold climates). The system shall support cost-effective operations and maintenance to conform with service provider resources and consumer needs.

4.1.7 Service Evolution

The system shall support the evolutionary nature of user services to accommodate advancements in technology, transportation and communications infrastructure, and resource development, public/private partnership arrangements, interjurisdictional cooperative agreements, and the dynamic service marketplace. The system shall support seamless service transitions from development and operational tests, early deployments, independent and future service incorporation, and service and technology upgrades.

4.1.8 Variations in Service Configurations

The system shall allow for variations in service configurations, operations, and technologies based upon service deployment priorities. The system shall provide integrated configurations, ranging from a single-user service to the entire 30 services. The system shall also promote interchangeability of service components provided by multiple original equipment manufacturers (OEM) and licensed vendors, through application of industry-standard and formal interfaces to the maximum extent possible. The system shall be flexible to support various service configurations, based upon variations that include service area priorities, market conditions, and environmental scenarios (i.e., urban, interurban, and rural).

4.2 User Requirements

This section provides a list of user requirements based upon analysis of the system-level requirements and identified users.

4.2.1 Generic

4.2.1.1 User Services

The system shall provide the complete set of user services.

4.2.1.2 System Interface

The system shall provide the user with multiple methods of interfacing with the system. For example, a traveler could plan his trip initially via one of the independent service providers. The traveler, once en-route to the destination, would have the opportunity to use the in-vehicle system to receive travel advisories and updated route guidance.

4.2.1.3 User Interface

The system’s user interfaces shall be designed for ease of understanding and use, to minimize ambiguity, and to provide the proper level of detail to match the user’s needs. For example, the kiosks located at area malls provide a menu of services that are easily discernible and selectable by a potential traveler.

4.2.1.4 Seamless Travel

The system shall appear to the user to be seamless across modes and geography. For example, as a traveler transitions from a commuter train to a city bus, no extraordinary actions would be required to continue the trip (i.e., no additional bus pass purchases, no further trip planning, unless so desired).

4.2.1.5 Seamless Payment

The system shall have a payment system that is seamless to the user. For example, a single debit card could provide toll, parking, and public transportation payments.

4.2.1.6 Types/Levels of Service

The system shall offer types and levels of service according to the user's desires. For example, a traveler would have the ability to plan a simple bus trip to the mall, or perform elaborate route selection functions necessary to travel across the country.

4.2.1.7 Mobility

The system shall increase mobility and the reliability/predictability of mobility (e.g., reduce travel time variances). For example, the system would provide up-to-date information on public transportation schedule adherence, which would inform the traveler of any delays.

4.2.1.8 Privacy

The system shall provide provisions to protect the user's privacy (e.g., vehicle probe use would be cooperative and voluntary).

4.2.1.9 Incremental Benefit

The system shall provide benefits that increase both incremental deployment and individual investment. For example, a simple radio would provide a driver with current traffic congestion data. However, if sufficient in-vehicle equipment was purchased, the driver would then be able to receive custom travel advisory information and dynamic route guidance.

4.2.2 Driver

4.2.2.1 Equipment Affordability

The system's in-vehicle equipment cost to the driver shall be affordable. A range of price/performance options shall be supported. Like most new technologies, AVLS will initially be expensive. As the technology matures, the price will decrease while performance increases.

4.2.3 Traveler

4.2.3.1 Choices

The traveler shall have a choice of routes, modes, departure times, parking, and other services appropriate to traveler needs. For example, at a mall kiosk, a traveler might have a choice of a taxi or a bus, with departure times every half hour.

4.2.3.2 Multiple Modes

The traveler shall have the option to plan trips requiring multiple transportation modes. For example, a traveler may plan a trip that involves bus transportation to a subway station, followed by subway transportation to the downtown district. This requirement satisfies both driving travelers (drivers) using mixed modality travel, and non-driving travelers (non-drivers) using ITS services.

4.2.4 Operator

4.2.4.1 Traffic Management

The system shall provide the traffic management operator with the functions required to effectively manage the traffic system.

4.2.4.2 Transit Operations

The system shall provide the transit operator with the functions required to effectively operate the transit system.

4.2.4.3 External Interfaces

The system shall provide the traffic management and transit operator with the appropriate communication methods for communicating with external entities, such as emergency management centers and the weather service.

4.2.5 Fleet Manager

4.2.5.1 Government Interface

The system shall provide the commercial fleet manager the capability to interface with appropriate government agencies regarding permits, licenses, etc.

4.2.5.2 Vehicle Management

The system shall provide the commercial fleet manager with current fleet status on vehicle locations and routes.

4.2.6 Other Users

The system shall provide interfaces for other external users of ITS (e.g., information brokers, financial clearinghouses, etc.). For example, an interface shall be provided for event promoters to notify traffic managers of upcoming events.

4.3 Performance Requirements

This section includes performance requirements that influence characteristics of the system. The requirements have been analyzed for each user service. Performance requirement ranges will be used to reflect performance sensitivities to implementation. Many of these “requirements” are actually guidelines to support evaluation of the architecture and evaluatory designs. Especially for information services, no real-time deadlines actually exist. The listed requirements provide one estimate of performance necessary for a useful service in a typical scenario.

The numbers should not be interpreted as minimum performance measures that will be levied on the implementor as firm constraints. Performance requirement values included here are provided without detailed analysis. These values can change significantly as further analysis and refinement is done, as the system matures, and system evaluation proceeds. The value "real-time" is used loosely to denote a time between instantaneous and a few seconds, while current is used loosely to denote a time between "real-time" and a few minutes.

4.3.1 Pre-Trip Travel Information

4.3.1.1 Communication

The system shall support two-way communication between data collection systems and data processing systems. The system shall also support communication between data processing systems and users.

4.3.1.2 Information Management

The system shall support collection, management, and access to current information on available services, traffic conditions, and trip planning. Pre-trip travel information includes current public transportation data and highway condition data. This is based on estimates of accessing current automated services (e.g., automated telephone banking services and automated teller machines).

4.3.1.3 Processing Time

Depending on the level of service, response time could range between 1 second and a few minutes.

4.3.1.4 Presentation

The system shall present travel information to properly fitted equipment.

4.3.2 En-Route Driver Information

4.3.2.1 Communication

The system shall support "real-time" communications to transfer present information to the driver. Information shall be transferred between information advisory sources, properly equipped vehicles, signs, and in-vehicle signing equipment.

4.3.2.2 Driver Advisory Presentation

The system shall provide accurate driver advisory information. The system shall provide in-vehicle signing within a necessary range for the communication media. This could be from 100 to1500 feet between the transmitter and vehicle for short-range communications, to a few miles for highway advisory information.

4.3.2.3 In-Vehicle Presentation

The system shall present in-vehicle advisory information and signing in audible and/or visible forms. The system shall, when considering this requirement, conform to safety and human factors.

4.3.3 Route Guidance

4.3.3.1 Communication

The system shall support "real-time" two-way communications from the transportation infrastructure to properly equipped vehicles.

4.3.3.2 Vehicle Location

The system shall provide vehicle location with a position accuracy appropriately meeting or exceeding the guidance requirements. Some level of service may require only a very coarse range (e.g., 300 feet for simple warnings such as upcoming exits or turns), while other levels of service require more precise information (1-20 feet) to identify the correct lane.

4.3.3.3 Processing Time

Depending on the level of service, the response time could range between a fraction of a second and a few minutes.

4.3.3.4 Presentation

The system shall provide "real-time" presentation to properly equipped vehicles.

4.3.3.5 Autonomous Route Guidance

The system will support autonomous route guidance in the absence of two-way communication.

4.3.4 Ride Matching and Reservation

4.3.4.1 Communication

The system shall support two-way communication between traffic information sources, ride matching and reservation services, billing services, and ride sharing personnel.

4.3.4.2 Information Management

The system shall support collection, management, and access to current information on riders, transportation providers and billing.

4.3.4.3 Processing Time

Depending on level of service, response time could range between 1 second and a few minutes.

4.3.4.4 Presentation

The system shall present ride matching and reservation information to properly fitted equipment.

4.3.5 Traveler Service Information

4.3.5.1 Communication

The system shall support two-way interactive communications between traveler service providers, sponsors, and users.

4.3.5.2 Information Management

The system shall support collection, management, and access to current database information on traveler services.

4.3.5.3 Processing Time

Depending on the level of service, response time could range between 1 second and a few minutes.

4.3.5.4 Presentation

The system shall present traveler service information to properly equipped interactive equipment.

4.3.6 Traffic Control

4.3.6.1 Communication

The system shall support two-way communications between control devices, traffic control / management centers, and surveillance equipment.

4.3.6.2 Information Management

The system shall support "real-time" collection, management, and access of current traffic surveillance and control parameters.

4.3.6.3 Processing

The system shall provide processing of areawide surveillance data, incident reports, and historical time-of-day patterns.

4.3.6.4 Control

The system shall provide traffic control through time-of-day/week (TOD/TOW), traffic responsive, and traffic demand prediction techniques.

4.3.6.5 Presentation

The system shall present current traffic condition data.

4.3.6.6 Surveillance Information

The system shall provide selective surveillance information.

4.3.7 Incident Management

4.3.7.1 Communication

The system shall support "real-time" two-way communications between information sources, responding agencies, and traffic management centers.

4.3.7.2 Surveillance Information

The system shall access current traffic surveillance information on a real-time basis, as available.

4.3.7.3 Incident Detection

The system shall reliably detect incidents. Incident detection time shall be optimized to provide the appropriate trade-off between probability of detection and false alarm rate. A system goal is to detect severe incidents (life threatening) with a high probability (e.g., greater than 95 percent) within a short time (e.g., less than 2 minutes). False alarm rates depend on verification capabilities. Significant verification facilities would allow for a higher detection false alarm rate. The goal is to have no false alarms after verification.

4.3.7.4 Incident Verification

The system shall provide "real-time" incident verification capabilities (i.e., video, electromagnetic, etc.) for control, presentation, and verification by system operators.

4.3.7.5 Incident Classification

The system shall provide incident classification capabilities to classify the type of incident allowing the operator to plan a proper response.

4.3.7.6 Incident Response

The system shall facilitate incident response formulation and execution when commanded by the system operator. Potential response options includes notifiying the appropriate agencies (i.e., law enforcement, emergency medical services, fire, HAZMAT, railroads, towing agencies, etc.).

4.3.7.7 Incident Coordination

The system shall facilitate incident response coordination through "real-time" information coordination/dissemination and status updates.

4.3.7.8 Incident Recordkeeping

The system shall accept system operator inputs for incident recordkeeping and collect incident response status for subsequent evaluation.

4.3.7.9 Incident Information Management

The system shall support "real-time" collection, management, and access of incident information statistics, responding agencies and resource status, response actions and status, and traffic network status.

4.3.7.10 Presentation

The system shall present incident detection status in "real-time".

4.3.8 Demand Management Operations

4.3.8.1 Communication

The system shall support real-time communications between transportation operators, traffic management centers, traffic surveillance equipment, parking areas, traveler status, etc.

4.3.8.2 Information Management

The system shall support collection, management, and access of current database information on travel services, traffic conditions, roadway and weather status, and trip planning.

4.3.8.3 Processing Time

The system shall provide current travel demand computation and travel demand management.

4.3.8.4 Presentation

The system shall present current travel demand information.

4.3.9 Emissions Testing and Mitigation

The system shall support emissions collection and testing in order to identify vehicles emitting levels of pollutants that exceed state, local, or regional standards. The system shall support emissions mitigation by providing information to drivers or fleet operators, enabling them to take corrective action.

4.3.10 Highway-Rail Intersection

Highway-rail intersection safety is interrelated with several other user services. Reference the Traffic Control, Driver Advisory, Incident Management, and Intersection Collision Avoidance User Services for other applicable requirements.

4.3.10.1 Communication

The system shall provide "real-time" communication between the wayside interface equipment, the highway-rail intersection, and appropriately equipped affected vehicles.

4.3.10.2 Supported Vehicles

The system shall support appropriately equipped vehicles at operating highway speeds.

4.3.10.3 Route Guidance Information

The system shall provide train schedules, with projected HRI closure times and duration, to drivers to alleviate schedule delays and include planned route coordination.

4.3.10.4 Driver Advisory Presentation

The system shall provide accurate driver advisory information. The system shall provide in-vehicle signing within a necessary range for the communication media. This could be from 100 to 1500 feet between the transmitter and vehicle for short-range communications, to a few miles for highway advisory information.

4.3.10.5 Safety Monitoring

The system shall provide system monitoring and provide critical safety problem or potential emergency warnings, with updates every few seconds.

4.3.10.6 Vehicle Detection Information

The system shall provide "real-time" vehicle detection information.

4.3.10.7 In-Vehicle Infrastructure Condition Warning

The system shall provide "real-time" detection and warning of unsafe infrastructure conditions from within the vehicle.

4.3.10.8 Display and Safety Warnings

The system shall provide monitoring displays with continuous monitoring of safety-critical systems, and provide safety-critical problem warnings or potential emergency warnings to the driver in near "real-time". These display and safety warnings shall be provided to rail operators and traffic management on exception basis or at periodic intervals, and to the inspection facility following query receipt.

4.3.11 Public Transportation Management

4.3.11.1 Communication

The system shall provide "real-time" communication between appropriately equipped public transportation vehicles, public transportation facilities, and emergency assistance facilities.

4.3.11.2 Vehicle Identification

The system shall provide vehicle identification capability.

4.3.11.3 Vehicle Location

The system shall provide vehicle location, with the capability to support fixed route and flexible route scheduling.

4.3.11.4 Route Guidance Information

The system shall provide public transportation drivers and dispatchers with current optimum routing information, to alleviate schedule delays and include planned route connection coordination.

4.3.11.5 Traffic Signal Preemption

The system shall include an integrated traffic control capability that provides traffic signal preemption as required, to adjust the schedule of transit vehicles at traffic signals.

4.3.11.6 Data Collection

The system shall support the current collection of data for planning and scheduling of public transit operations, and driver and maintenance personnel management.

4.3.11.7 Information Management and Analysis

The system shall support off-line transit information management and analysis of data for planning and scheduling of public transit operations, and driver and maintenance personnel management.

4.3.12 En Route Transit Information

4.3.12.1 Communication

The system shall support "real-time" communication between transit advisory sources and properly fitted equipment (i.e., advisory information should be nearly instantaneous for significant use by transit and high-occupancy vehicles).

4.3.12.2 Information Management

The system shall support collection, management, and access to current information on traffic conditions and trip planning.

4.3.12.3 Processing Time

Depending on the level of service, response time could range between 1 second and a few minutes.

4.3.12.4 Presentation

The system shall present transit advisory information to properly equipped interactive equipment.

4.3.13 Personalized Public Transit

4.3.13.1 Communication

The system shall provide "real-time" communication between appropriately equipped transportation vehicles, transportation facilities, and passengers.

4.3.13.2 Vehicle Identification

The system shall provide vehicle identification capability.

4.3.13.3 Vehicle Location

The system shall provide vehicle location with position accuracy capable of supporting demand-responsive transit operations and dispatch.

4.3.13.4 Routing Information

The system shall provide transportation drivers and dispatchers with current routing information in response to passenger reservations, and provide passengers with near real-time reservation confirmation and imminent arrival notification.

4.3.13.5 Service Hours

The system shall provide continuous access to service.

4.3.13.6 Service Optimization

The system shall provide optimum passenger ride time and convenience.

4.3.13.7 Passenger Pick-up

The system shall provide vehicle assignment to pick-up passengers within a 4-block radius of all trip origination sites in the area.

4.3.13.8 Passenger Information

The system shall provide real-time access to passenger information.

4.3.14 Public Travel Security

4.3.14.1 Communication

The system shall provide "real-time" communication from appropriately equipped facilities and mobile units to central dispatch or the local police.

4.3.14.2 Surveillance Information

The system shall provide continuous surveillance service.

4.3.14.3 Alarms

The system shall provide "real-time", traveler-activated alarms, to include all physical areas related to public travel. In addition, the system shall provide silent, activated alarms on board public transit vehicles capable of activation by the driver.

4.3.14.4 Passenger Identification and Location

The system shall provide passenger identification, location, and incident status information within 5 minutes of message receipt.

4.3.15 Electronic Payment Services

4.3.15.1 Communication

The system shall support "real-time" communication between electronic payment facilities, electronic payment services, and appropriately equipped vehicles.

4.3.15.2 Information Management

The system shall support collection, management, and access of current driver and rider eligibility information. The system shall support off-line storage of driver levels and ridership levels for specific routes requiring transit operator scheduling and route planning.

4.3.15.3 Transaction Processing

The system shall verify electronic payment to the traveler while the traveler waits. Typical response times should be between 1 and 10 seconds.

4.3.16 Commercial Vehicle Electronic Clearance

4.3.16.1 Vehicle-Infrastructure Communication

The system shall provide two-way "real-time" communication between appropriately equipped commercial vehicles and the infrastructure.

4.3.16.2 Supported Vehicles/Carriers

The system shall support interstate/intrastate commercial vehicles/carriers operating at highway speeds.

4.3.16.3 Detection Range and Accuracy

The system shall provide vehicles/carriers identification and weight. This could be provided upstream from the inspection facility, to allow time for appropriate “pull-in” messages.

4.3.16.4 Information Management

The system shall support collection, management, access, and coordination of current information at roadside inspection facilities.

4.3.17 Automated Roadside Safety Inspection

4.3.17.1 Vehicle-Infrastructure Communication

The system shall provide two-way "real-time" communication between appropriately equipped commercial vehicles and the infrastructure.

4.3.17.2 Supported Vehicles/Carriers

The system shall support interstate/intrastate commercial vehicles/carriers at operating highway speeds.

4.3.17.3 Information Management

The system shall support collection, management, access, and coordination of current information at automated roadside inspection facilities.

4.3.17.4 Brakes Inspection

The system shall provide brakes inspection after the vehicle/carrier enters the inspection facility.

4.3.17.5 Vehicle Diagnostics

The system shall provide vehicle diagnostics at automated roadside inspection facilities.

4.3.17.6 Driver Diagnostics

The system shall provide driver diagnostics at automated roadside inspection facilities.

4.3.18 On-Board Safety Monitoring

4.3.18.1 Vehicle-Infrastructure Communication

The system shall provide two-way, "real-time" communication between appropriately equipped commercial vehicles and the infrastructure. The system shall support "real-time" on-board sensor monitoring and warning control.

4.3.18.2 Supported Vehides/Carriers

The system shall support interstate and intrastate commercial vehicles/carriers at operating highway speeds.

4.3.18.3 Critical On-Board Subsystem Monitoring and Storage

The system shall monitor vehicle component conditions and driver conditions from on-board the vehicle, and provide data storage every few minutes.

4.3.18.4 Display and Safety Warnings

The system shall provide monitoring displays with continuous monitoring of safety-critical systems, and provide safety-critical problem warnings or potential emergency warnings to the driver in near "real-time". These display and safety warnings shall be provided to the fleet manager on exception basis or at periodic intervals, and to the inspection facility following query receipt.

4.3.18.5 Driver and Vehicle Identification

The system shall provide driver and vehicle identification to the inspection facility.

4.3.18.6 Information Management

The system shall support collection, management, and access of current information at roadside inspection facilities.

4.3.19 Commercial Vehicle Administrative Processing

4.3.19.1 Vehicle-Infrastructure Communication

The system shall provide two-way, "real-time" communication between appropriately equipped commercial vehicles and the infrastructure.

4.3.19.2 Supported Vehicles/Carriers

The system shall support interstate and intrastate commercial vehicles/carriers at operating highway speeds.

4.3.19.3 Border Preclearance

The system shall provide pre-clearance processing at international borders. The system shall support "real-time" processing of commercial vehicle pre-clearance information, credentials, and cargo status.

4.3.19.4 Mileage Recording

The system shall provide mileage recording.

4.3.19.5 Electronic Credential Transaction

The system shall provide electronic purchase of credential.

4.3.20 Hazardous Material Incident Response

The system shall identify, verify, and classify the hazardous material.

4.3.21 Freight Mobility Management

4.3.21.1 Communication

The system shall provide "real-time" communication between commercial vehicles, commercial vehicle drivers, dispatchers, commercial fleet management centers, and intermodal transportation providers.

4.3.21.2 Route Guidance Information

The system shall provide commercial drivers and dispatchers with current routing information in response to congestion or incidents.

4.3.21.3 Vehicle Identification

The system shall provide vehicle and/or cargo identification.

4.3.21.4 Vehicle Location

The system shall provide vehicle and/or cargo location.

4.3.22 Emergency Notification and Personal Security

4.3.22.1 Communication

The system shall provide real-time communication from appropriately equipped vehicles to at least one response unit at all times from any location in the United States.

4.3.22.2 Vehicle Location

The system shall provide vehicle location with position accuracy available to the communication media. This location information may be very coarse when provided by triangulation on cellular type communications (e.g., 125 feet), or very precise when provided by GPS with differential correction (e.g., less than 1 foot), which includes latitude, longitude, and altitude.

4.3.22.3 Emergency Notification

The system shall provide manual and automatic initiation of emergency notification within 1 minute.

4.3.22.4 Critical In-Vehicle Subsystem Monitoring

The system shall monitor vehicle component conditions from inside a vehicle every few minutes, and, for critical emergency condition cases, automatically send the appropriate distress signal.

4.3.23 Emergency Vehicle Management

4.3.23.1 Communication

The system shall provide "real-time" communication between the following: the dispatcher and the traffic signal, the appropriately equipped emergency vehicles and appropriately equipped affected vehicles, and the appropriately equipped emergency vehicles and traffic signal controls for right-of-way.

4.3.23.2 Emergency Fleet Management

The system shall provide "real-time" emergency vehicle fleet management.

4.3.23.3 Vehicle Identification

The system shall provide vehicle identification.

4.3.23.4 Vehicle Location

The system shall provide vehicle location.

4.3.23.5 Traffic Signal Prioritization

The system shall provide "real-time" traffic signal prioritization by maintaining current information on signal timing, emergency vehicle locations, and emergency vehicle routing.

4.3.24 Longitudinal Collision Avoidance

4.3.24.1 Supported Vehicles

The system shall support appropriately equipped vehicles at operating highway speeds.

4.3.24.2 Front or Rear of Vehicle Sensing

The system shall provide sensing of potential or impending collisions, or dangers to the front/rear of the vehicle, with range depending on closing rate and vehicle dynamics.

4.3.24.3 Driver Collision Avoidance Action Elicitation

The system shall provide the driver a collision avoidance action elicitation, when sensing a potential or impending collision, or danger to the front/rear of the vehicle.

4.3.24.4 Temporary Automatic Control

The system shall provide temporary automatic control of the vehicle, when sensing an impending collision.

4.3.24.5 Autonomous Intelligent Cruise Control

The system shall provide autonomous intelligent cruise control of the vehicle.

4.3.24.6 Vehicle and Driver monitoring

The system shall provide critical in-vehicle subsystem and driver monitoring, with updates every few seconds.

4.3.24.7 Display and Safety Warning

The system shall provide system monitoring display and critical safety problem or potential emergency warnings, with updates every few seconds.

4.3.25 Lateral Collision Avoidance

4.3.25.1 Supported Vehicles

The system shall support appropriately equipped vehicles at operating highway speeds.

4.3.25.2 Blind-spot Sensing

The system shall provide sensing of vehicles in the driver's blind spots.

4.3.25.3 Blind-spot Information and Display

The system shall provide "real-time" information and display the presence of vehicles in the driver's blind spots.

4.3.25.4 Potential collision due to lane change warning

The system shall provide "real-time" warning of potential collisions due to lane change or merging activities initiated by the driver.

4.3.25.5 Driver Collision Avoidance Action Elicitation

The system shall provide the driver a collision avoidance action elicitation within 3 seconds after sensing a potential or impending collision, or danger due to lane changing or merging activities initiated by the driver.

4.3.25.6 Temporary Automatic Control

The system shall provide temporary automatic control of the vehicle, when sensing an impending collision.

4.3.25.7 Lane maintenance

The system shall provide proper lane maintenance of the vehicle.

4.3.25.8 Vehicle and Driver monitoring

The system shall provide critical in-vehicle subsystem and driver monitoring, with updates every few seconds.

4.3.25.9 Display and Safety Warning

The system shall provide system monitoring display and provide critical safety problem or potential emergency warnings, with updates every few seconds.

4.3.26 Intersection Collision Avoidance

4.3.26.1 Supported Vehicles

The system shall support appropriately equipped vehicles at operating highway speeds.

4.3.26.2 Vehicle Detection

The system shall provide vehicle detection.

4.3.26.3 Vehicle Detection Information

The system shall provide "real-time" vehicle detection information for direct vehicle use and/or driver display.

4.3.26.4 Driver Collision Avoidance Action Elicitation

The system shall provide the driver an intersection collision avoidance action elicitation within 3 seconds after sensing of potential or impending intersection collision.

4.3.26.5 Temporary Automatic Control

The system shall provide temporary automatic control of the vehicle to avoid an intersection collision.

4.3.26.6 Vehicle and Driver monitoring

The system shall provide critical in-vehicle subsystem and driver monitoring, with updates every few seconds.

4.3.26.7 Display and Safety Warning

The system shall provide system monitoring display and provide critical safety problem or potential emergency warnings, with updates every few seconds.

4.3.27 Vision Enhancement for Crash Avoidance

4.3.27.1 In-vehicle Sensing

The system shall provide "real-time" in-vehicle sensing for outside scene imaging.

4.3.27.2 Visual Display

The system shall provide a "real-time" visual display of an image. These displays may include graphical representations of the image.

4.3.27.3 Vehicle Monitoring

The system shall provide critical in-vehicle subsystem monitoring, with updates every few seconds.

4.3.27.4 Display and Safety Warning

The system shall provide system monitoring display and provide critical safety problem or potential emergency warnings with updates every few seconds.

4.3.28 Safety Readiness

4.3.28.1 Supported Vehicles

The system shall support appropriately equipped vehicles at operating highway speeds.

4.3.28.2 Impaired Driver Warning

The system shall provide in-vehicle monitoring of various driver performance features and displays with updates every few seconds.

4.3.28.3 Vehicle Condition Warning

The system shall provide in-vehicle monitoring of safety-critical components and provide warnings with updates every few seconds.

4.3.28.4 In-Vehicle Infrastructure Condition Warning

The system shall provide "real-time" detection and warning of unsafe infrastructure conditions from within the vehicle.

4.3.28.5 Vehicle Monitoring

The system shall provide critical in-vehicle subsystem monitoring, with updates every few seconds.

4.3.28.6 Display and Safety Warning

The system shall provide system monitoring display and provide critical safety problem or potential emergency warnings, with updates every few seconds.

4.3.29 Pre-Crash Restraint Deployment

4.3.29.1 Supported Vehicles

The system shall support appropriately equipped vehicles at operating highway speeds.

4.3.29.2 Anticipate Imminent Collision

The system shall provide "real-time" imminent collision anticipation information.

4.3.29.3 Activate Passenger Safety Systems

The system shall provide "real-time" automated activation of passenger safety system.

4.3.29.4 Vehicle Monitoring

The system shall provide critical in-vehicle subsystem monitoring, with updates every few seconds.

4.3.29.5 Display and Safety Warning

The system shall provide system monitoring display and provide critical safety problem or potential emergency warnings, with updates every few seconds.

4.3.30 Automated Highway System

4.3.30.1 Infrastructure-Vehicle Communication

The system shall provide two-way, "real-time" communication between the infrastructure and appropriately equipped vehicles.

4.3.30.2 Vehicle-Vehicle Communication

The system shall provide two-way, "real-time" communication between appropriately equipped vehicles.

4.3.30.3 Supported Vehicles

The system shall support appropriately equipped vehicles at operating highway speeds.

4.3.30.4 Automated Highway System (AHS)

The system shall provide an AHS as the "real-time" automated vehicle operations operating platform.

4.3.30.4.1 Automated Check-In

The system shall provide automated check-in for access onto the AHS within 3 seconds, or as determined by the National Automated Highway System Consortium.

4.3.30.4.1.1 Vehicle Qualification

The system shall provide diagnostics to determine vehicle qualification for access to the AHS.

4.3.30.4.2 Automated Vehicle Control

The system shall provide automated control of appropriately equipped vehicles on the AHS.

4.3.30.4.2.1 Vehicle and Driver Monitoring

The system shall provide critical in-vehicle subsystem and driver monitoring, with updates every few seconds.

4.3.30.4.2.2 Display and Safety Warning

The system shall provide system monitoring display and provide critical safety problem or potential emergency warnings, with updates every few seconds.

4.3.30.4.3 Automated Check-Out

The system shall provide automated check-out for exit from the AHS at designated points.

4.3.30.4.3.1 Driver Readiness

The system shall provide "real-time" driver alertness testing, within an accuracy of 99.99% prior to automated check-out.

4.3.30.5 Partially Automated Highway System (PAHS)

The system shall provide the PAHS as a transitional, partially automated, "real-time" vehicle operation.

4.3.30.5.1 Critical Vehicle Subsystems

The system shall provide "real-time" automated vehicle control service functions to implement transitional levels of performance.

4.3.30.5.2 Vehicle and Driver Monitoring

The system shall provide continuous critical in-vehicle subsystem and driver monitoring, with updates every few seconds.

4.3.30.5.3 Display and Safety Warning

The system shall provide system monitoring display and critical safety problem or potential emergency warnings, with updates every few seconds.

4.4 System Constraints and Life Cycle Factors

The system shall support user services within the following system constraints and life cycle factors. These specialized requirements define the functional "boundaries" or constraints the system must operate within, to provide reliable, accurate, and seamless services. Life cycle factors define requirements for the "quality" of service needed to satisfy system goals and objectives.

4.4.1 Service Availability

The system shall support configurations and technologies that provide cost-effective implementation and reliable services. System support for service availability shall provide a consistent level of quality between service providers, geographic locations, or compatible system configurations. When services are offered, the system shall meet 99% overall service availability. Service availability shall be measured in terms of overall operating time to service downtime, due to equipment failures and routine maintenance.

4.4.2 Reliability

The system shall support service reliability in proportion to associated criticality levels (i.e., safety, information transactions, advisories/warnings, etc.). The system shall balance service criticality with the cost associated with deployment, operation, and maintenance of the service (i.e., allocated, opportunity, time, flexibility, and risk).

4.4.3 Maintainability

The system shall incorporate maximum use of standardized, commercial-off-the-shelf (COTS) products and technical services. Standardized is defined as modular products and technical services that provide a service function through industry-standard interfaces. The system shall support maintainability factors associated with a system maintenance program, including OEM/licensed vendor technical support, funding, budgeting, and service provider staffing resources. These factors provide general requirements for a system maintenance concept, types of maintenance, and maintenance services.

4.4.3.1 Maintenance Concept

The system shall support a modular maintenance concept. The system shall incorporate technologies, equipment, components, and subsystems that support modular designs for ease of maintenance by service providers. The system shall incorporate a minimum of two levels of maintenance: 1) service-level, and 2) component-level. Service-level maintenance consists of those activities associated with service provider operations and maintenance (i.e., organizational removal and replacement of hardware components and software, functional information database updates, service sales, staffing resources, etc.). Component-level maintenance consists of detailed hardware and software maintenance that cannot be performed at the service level. This includes OEM and vendor maintenance and repair.

4.4.3.2 Types of Maintenance

The system shall support functional and system maintenance categories within each maintenance level. Functional maintenance consists of activities associated with functional operation of the system or service (i.e., recurring database updates, cost/billing accounting, staffing, etc.). System maintenance shall consist of activities associated with system hardware, software maintenance, and repair actions.

For hardware, three levels of maintenance priority are addressed: 1) remedial maintenance to restore operations due to equipment malfunctions and failures; 2) preventive maintenance to minimize the probability of failure during the product design life; and 3) modification/ reconstruction maintenance to remedy manufacturing or design flaws, or to incorporate hardware improvements that enhance overall equipment characteristics and performance.

For software, a continuous level of maintenance shall be addressed to maintain, improve, and enhance system operations. For service deployment, system software shall incorporate, as a minimum, the following characteristics to minimize software failures and problems, and reduce their impact to manageable proportions.

- Employ verified or proven software packages.
- Utilize software packages which are written in a compiler-level language.
- A complete set of accurate software documentation, including user's manuals and compiler listings.

4.4.3.3 Maintenance Services

The system shall incorporate commercial-off-the-shelf (COTS) modules, equipment, components, and subsystems that can be maintained through native (service provider) maintenance organizations. An alternative maintenance approach shall be to have maintenance tasks performed by purchased services.

4.4.4 System Safety

The system shall incorporate safety features to protect individuals, property, and the surrounding infrastructure environment.

4.4.4.1 Critical Operations

The system shall isolate safety-critical operations into manageable modules. For these modules, the system shall incorporate adequate safety features (i.e., redundancy, limited access, lockout, information presentation limits, etc.) to minimize the probability and impact of safety-related failures.

4.4.4.2 Operator Interfaces

The system shall provide special consideration to operator interfaces/human factors for all aspects of user services (i.e., in-vehicle, roadside, public access, control center environments, etc.).

4.4.4.3 Safe Service Operation

The system shall provide safe service operation in all modes of operation. The system shall provide safe and available service operation in degraded modes of operation and performance.

4.4.5 Producibility

The system shall support service configurations so that service components can be produced in a cost-effective manner.

4.4.5.1 Design for Producibility

The system shall support designs that incorporate standardized technologies, interface definitions, and processes that promote cost-effective system operations and maintenance. The system shall provide for evolutionary durability.

4.4.5.2 Industry-Standard Interfaces

The system shall incorporate maximum use of industry-standard interfaces to allow module, component, and subsystem interchangeability between multiple OEMs/licensed vendors.

4.4.6 Supportability

The system shall incorporate services, technologies, equipment, components, and subsystems when a compatible product base is supported through multiple OEMs/licensed vendors. Support is defined as OEM/licensed vendor technical services, and product warranties and repair, to extend a minimum duration of five years from the date of deployment or procurement. System support shall be consistent with the product’s design life.

4.4.7 Human Factors

The system shall provide travel-related information necessary to support a range of mobile (i.e., in-vehicle, personal, etc.), fixed, portable facility (i.e., roadside, public access, etc.), and command/coordination facility display devices (i.e., traffic management, fleet management, transit management, etc.). Information shall be conveyed through audio, visual, and tactile forms. These range from simple binary warning lights, indicator lights, auditory alarms, and messages, to text message displays, graphics displays, video, and virtual displays.

4.4.7.1 System Response

The system shall respond to user information requests and service requests in a timely manner. Information value shall consist of adequate recency, accuracy, and frequency as required by the user's tasks and travel conditions.

4.4.7.2 Information and Service Utility

The system shall provide sufficiently reliable information and services to gain the user’s trust and achieve long-term system acceptance and market viability.

4.4.7.3 Training Support

The system shall support standardized training approaches, familiarizing users, maintenance technicians, operators, managers, and other personnel with proper use of system/service devices, components, technologies, operations, and management strategies. The skills required for system operation may be obtained through the service implementor, independent sources, and on-line training features.

4.4.8 System Security and Integrity

The system shall provide adequate protection for critical service information, safety-critical components and modules, and high-value operational-critical components. Subsystems shall be provided protection from fraud, misuse, inadvertent or unauthorized access, and malicious tampering or destruction. The system shall provide adequate protection from inadvertent and malicious attacks against modification/loss of high-value information, equipment, and facilities. The system shall employ means and methods to detect and preclude unauthorized access, tampering, and destruction of critical system/service information and components.

4.4.9 System Compatibility

The system shall provide nationwide user service compatibility when comparable services are offered. The system shall provide industry-standard interfaces to accept and incorporate compatible service provider components, equipment, subsystems, and infrastructures as a means to demonstrate system openness. The system shall incorporate industry-standard or formal interface definitions to promote interoperability between user services, components, equipment, and subsystems. The system shall promote component, equipment, and subsystem interchangeability among OEM and licensed vendors.

4.4.10 System Environments

The system shall operate in general environments (e.g., topographical), operational temperatures, humidity, lightning/electrostatic discharge, radio frequency interference/ electromagnetic interference, wind/salt/sand/dust/contaminants, and other environmental effects commonly found in urban, interurban, and rural settings across the continental United States.

4.5 Program Requirements

The system shall configure user services to incorporate system deployment, institutional, political, and legal requirements. These services shall include provisions to promote cost-effective implementation, operations and maintenance, market acceptance, service viability, inter-jurisdictional cooperation, political support, and equitable distribution of legal responsibility.

4.5.1 Deployment Requirements

The system shall support an evolutionary deployment strategy that targets market needs to achieve early benefits, promote cost-effective operations, and support maintenance approaches for evolution durability.

4.5.1.1 Public/Private Sector Opportunities and Benefits

The system shall accommodate public and private sector opportunities and benefits to promote early deployment and continued support. The system shall promote development of user services based on user and market needs, and provide immediate financial and mobility benefits to a developing market.

4.5.1.2 Adoption of Service Standards

The system shall support a range of technologies and provide a basis for adoption of standards (i.e., industry-wide, formal, etc.). The system shall incorporate technologies that stress upward capability, including compatible standards and open architecture features. These features provide the ability to upgrade an earlier deployment system, without completely replacing the original system.

4.5.1.3 Pre-planned Product/Service Improvements

The system shall incorporate pre-planned product improvement changes. The system shall incorporate deployment approaches to capitalize on future technology and service advancements. The system shall incorporate refinements relating to performance, producibility, reliability, availability, maintainability, supportability, unit cost, life cycle cost, and extended service life.

4.5.2 Institutional Requirements

The system shall provide a user service framework to promote and distribute immediate user benefits and affordable market costs.

4.5.2.1 Utilization of Existing Technologies and Infrastructures

The system shall be structured around existing technology "building blocks" (e.g., communication systems, sensors, geographic databases), many of which can be deployed as upgradeable, stand-alone subsystems.

4.5.2.2 Private Sector Investment

The system shall provide opportunities for private sector investment. Identifiable areas will aid the private sectors in making investments in key aspects of the system. These aspects promote the removal of barriers, competition, and reduces development costs. These aspects also improve public-private partnerships and cooperation.

4.5.2.3 Implementation Flexibility

The system shall support a range of implementations that meet various local funding and market constraints.

4.5.3 Institutional Requirements

The system shall support user service arrangements to promote inter-organizational cooperation and coordination.

4.5.3.1 Regional Management

The system shall provide for regional approaches to infrastructure management. The system shall provide for regional user service management approaches to coordinate hand-offs and information sharing, depending on user service needs.

4.5.3.2 Transportation Planning

Transportation planning among local traffic systems shall be coordinated within the system architecture. The system shall be designed to provide joint approaches for addressing problems and priorities, and provide solutions among the participating organizations during transportation planning.

4.5.3.3 Inter-organizational Cooperation

The system shall provide opportunities to facilitate cooperative relationships within and between organizations.

4.5.3.4 Institutional Conformance

The system shall abide by statewide and metropolitan area planning and ISTEA management systems relationships.

4.5.4 Political Provisions

The system shall incorporate governing ISTEA and Clean Air Act provisions. The system shall promote avenues for Government leadership to develop and disseminate given standards for those areas with compelling Government interest.

4.5.5 Legal Provisions

System shall provide provisions to limit and distribute liability among users, public service providers, private service providers, and system OEMs/licensed vendors. Manufacturers and government must submit to a common agreement with respect to service liability. The system shall promote development of a legislative framework, limiting and distributing liabilities, removing barriers to private sector participation, and promoting public-private partnerships.

4.5.5.1 Liability Legislation

Government shall implement appropriate legislation. Local, state, and federal legislation shall be implemented in agreement with system development, addressing conflicting or divergent views, interests, and objectives.

4.5.5.2 Inter-jurisdictional Enforcement

The system shall accommodate special legal arrangements that cross jurisdictional lines. The system shall accommodate multiple authorities for traffic law enforcement.

APPENDIX A

ITS Threat Analysis

A.1 Introduction

This section presents an analysis of the security and privacy threats to an ITS system architecture. Its purpose is to raise the security and privacy awareness of the ITS community (developers, sponsors, and stakeholders). The list of threats is not all-inclusive, but is intended only to indicate where possible abuse of the ITS could occur. This section also presents a brief summary of possible security and privacy techniques that can be applied to counter these threats.

A.1.1 Why are security and privacy important?

Security and privacy are important to the ITS architecture, because a computerized system that can track the movements of vehicles offers a variety of opportunities for abuse. If abuse was permitted to occur unchecked, this could, at a minimum, make the operation of ITS far more costly than expected, as criminals could commit fraud and theft against the fee-paid ITS services. The fraud and theft experienced could be in a manner currently being experienced by the widely rampant cellular telephone fraud. As public dependency on ITS grows, the need to protect the system from intentional disruption of services and control, or even the potential threat of such an attack, will certainly increase.

With the opportunity to track vehicle movement, inherently individuals could open up new opportunities for crime and abuse, ranging from harassment, computer-assisted auto theft, and hijacking, to computer-assisted kidnapping. Vehicle tracking also opens up opportunities to infringe upon the individual’s privacy rights. For example, a private detective or an investigative reporter might use ITS to track the movements of a public figure, or the target of a legal action or divorce proceeding. ITS also opens up opportunities for new forms of law enforcement that, while making the law enforcement more efficient, could also raise concerns of civil liberties and constitutional rights.

The combination of all of these potential security and privacy problems could impede the acceptance of ITS, either by the system architecture proving to be costly to operate, or the general public feeling uneasy about using it.

A.2 Classes of Threats

A.2.1 Theft Of Services

The simplest threats against ITS fall in the category of theft of services. These threats are analogous to the various forms of fraud that are widely committed today against the cellular telephone network. At a very high level, theft of services happens when an attacker convinces ITS to provide services to the attacker, but to either not charge for those services at all or to charge the services to someone else without their permission.

How can this occur? Let’s assume there is an electronic toll collection system. The vehicle transmits an identification code to the toll booth, and a charge is made against the driver's account for the amount of toll owed. An attacker could defraud such a system in a number of ways. First, the attacker could simply transmit an identification code chosen at random. If the toll collection system did not validate the code immediately, the driver might escape payment. This is analogous to the *tumbling fraud* that has been a serious problem in cellular telephony prior to the introduction of pre-validation systems. [1] If the identification code is immediately validated, then the attacker might transmit someone else's code. The attacker might obtain such a code by listening to the radio transmissions near a toll booth. This is analogous to the *cloning fraud* that is today a serious problem in cellular telephony. However, if the appropriate forms of cryptography were used in transmitting the identification code, then the attacker would be unable to steal an identification code simply by listening to the communications channels. Cryptographic protection is used in the GSM cellular systems in Europe and is part of the IS-41 standards for digital cellular in the US.

Cryptographic protection only addresses theft of services through abuse of the ITS communications system. Theft of services is also possible if an attacker can gain unauthorized access to computers that implement the toll collection system. Such an attack could occur in a number of ways. The computers might be connected to a network, or the attacker might gain access through a telephone dial-up connection. Most computer security problems are caused by insiders. A current or former employee of the highway authority might perpetrate an attack. Once into the computers, the attacker could steal cryptographic information while masquerading as another user, or could re-program the computers to never charge a toll for particular identification codes.

Evading the toll on a highway is a relatively small offense and does not involve a large sum of money; however, that same argument was made in the early days of cellular telephony to justify not implementing adequate security. Cellular fraud today costs the industry hundreds of millions of dollars per year, and is going up at an alarming rate. A criminal could make a lot of money selling devices to independent truckers, allowing them to avoid the toll charges. If the criminal had access to the computers directly, the cost of building such illegal devices would be very small, yet the criminal could sell them for several hundred dollars each.

A.2.2 Tracing Vehicle Or Individual Movements

A more sophisticated threat to ITS users is the illicit tracing of vehicle movements. With knowledge of vehicle movements, a variety of attacks are possible ranging from simple harassment to organized theft, terrorist kidnappings, and murders. A private detective could trace someone's movements to obtain evidence in a divorce proceeding. An investigative journalist could trace the movements of a prominent politician and perhaps expose information to use in a political campaign. More seriously, a deranged fan could stalk a celebrity, or an abusive spouse could trace the movements of someone protected by a court order. The operator of the ITS system might be faced with a massive liability lawsuit if someone were injured or killed through a security weakness that permitted tracing someone's movements.

Truck hijackers could make use of a system that traced the movements of a fleet of trucks, so as to select an optimal location for the hijacking and to be sure to hijack only trucks carrying the most valuable cargo. Criminals could use a vehicle tracing system to follow its intended victims for kidnapping. Corporate executives who might be targets are today encouraged to vary their routes to and from work to minimize potential exposures. However, if the criminal can query the computer to locate the vehicle, all such countermeasures could be nullified.

How could a vehicle be illicitly traced with ITS? Just as for theft of services, the most straightforward way is to listen to the radio broadcasts made by the vehicle. Even if digital signatures are used to deal with the theft of services problems, if the transmissions can be uniquely tied to a particular vehicle, that is sufficient to perform the trace. Several techniques could be used, depending on the ITS implementation strategy. For example, if only the digital signatures were encrypted, but the remainder of the messages were only integrity checked (a common approach in electronic funds transfer), then the attacker need only listen to the broadcasts. All of the relevant data is in the clear. Even if the data were all encrypted, if the system required clear text headers (such as used in most packet switching networks, even in the presence of end-to-end data encryption), then the vehicle could be tracked by the headers alone.

This attack is analogous to the problems first identified in [2]. One such equivalent of a clear text header might be a sequence number assigned to each trip for each vehicle. If a particular sequence number were observed leaving a truck depot heading for a particular destination, the attacker might be able to deduce that the sequence number corresponded to a particular vehicle on a particular trip. The details of such attacks would depend heavily on the architecture and implementation ultimately selected for ITS.

However, the penetration of the ITS computer system would offer the criminal a more powerful technique for tracing a vehicles movements. The ITS computer may already be tracking the vehicle, and without proper safeguards, key information about the users may be readily available to an attacker who penetrates the computer system. The attacker would not need to deploy additional sensors or antennas. The ITS computer provides all the necessary data.

Tracing an individual in a car or truck is generally more difficult than tracing the vehicle itself, because a vehicle may have multiple drivers. However, the attacker does not necessarily need 100% accuracy. An attacker could assume that if a vehicle always travels from a home to a particular work location, then the driver of that vehicle is probably the same person who works at that location. Errors might occur, if the driver occasionally swaps cars with other residents of that home, but the attacker could probably recognize those cases by analyzing the usual traveling patterns of all cars associated with that home.

Movements of individuals could also be traced through the ITS public-transit and ride-share related functions. Essentially, all attacks against a vehicle are possible against an individual, but with potentially higher accuracy. Tracking a vehicle does not necessarily track a particular individual, but tracking a public-transit rider does. Ride-sharing can be the most dangerous, as the computer could be used to match a target individual directly with an intended kidnapper, etc.

A.2.3 Influencing Traffic Patterns

A step beyond tracking vehicle movements is to illicitly influence vehicle movement. The illegal manipulation of individual vehicles and groups of vehicles is a sophisticated, yet possible threat to the ITS program.

How could an attacker control the movements of a vehicle? One way would be to create a bogus ITS system and trick the onboard vehicle system into communicating with the bogus system, rather than the real one. This might be accomplished by using a more powerful radio signal, or by tampering with transmitters. However, such interference could easily be discovered. The better way would again be to attack the ITS computers themselves and make the system itself transmit incorrect information.

What could be done with vehicle control? If the attacker could control trip planning information, it would be possible to illicitly redirect traffic . A truck hijacker might direct selected trucks to drive into an ambush. The owner of a roadside store or restaurant might try to redirect a larger volume of traffic to pass by his or her establishment. A criminal in a getaway car might try to redirect a larger volume of traffic behind the getaway car to make it more difficult for the police to conduct a high speed chase. Finally, if ITS offered fully automatic vehicle control, a criminal could take control of the target's vehicle and either drive it directly into an ambush, or deliberately cause an accident in the hope of killing the occupant.

To re-emphasize, these threats of controlling vehicle movements are less likely to be exploited. They require much higher sophistication on the part of the attacker, and are more likely to be discovered. They are included here for completeness.

A.2.4 Abridgment Of Civil Or Constitutional Rights

ITS can offer a number of possible services to law enforcement, some of which have been included in the list of major ITS user services from the FHWA. Many of these potential services focus on tracking the movement of vehicles involved in an on-going investigation. For example, if the police could identify an ITS-equipped getaway car escaping from the scene of a crime, they can request ITS to track the vehicle.

The police, in effect, avoid the dangers of a high-speed chase, allowing the computer to electronically "chase" the vehicle and direct the police to specific locations to set up roadblocks. A primitive form of this service is already offered by the Lo-Jack® system, which allows police to track a car that has been reported as stolen.

The problem with making these types of services available to law enforcement agencies is the possibility of their abuse. The police, being able to track the movements of any vehicle electronically, leads to visions of Orwell's *1984* [3], in which the government tracks the movements of all citizens to control their lives. Even mundane sorts of abuse could be possible. Consider what a country sheriff, who used to run speed traps against tourists passing by, could do with an ITS computer. He might electronically select passing tourists, stopping them for the purpose of enriching the town coffers or himself. The user services that are planned for ITS, of course, do not include speed trap features. However, once ITS computers are in place, adding such features would be simple.

It is important to recognize that abuse of the civil or constitutional rights that are being discussed are technically no different from the abuse described earlier. The data being misused is exactly the same. The difference is that this abuse could be performed by government agencies involved in traffic management or law enforcement, that is, people who have legitimate access to ITS databases, as opposed to outside intruders.

Clearly, there are issues regarding civil liberties and constitutional rights inherent in the use of ITS capabilities by law enforcement. It is important that the public debates these issues prior to the implementation of ITS services. It is beyond the scope of this document to address legal and ethical issues in detail. The purpose of this section is to document the existence and to start discussion of these issues. The solutions are not technical ones, but rather procedural and legal ones, to ensure that law enforcement agencies use this new technology appropriately, and do not abridge constitutional rights.

A.2.5 Competitive Threats

If, in a competitive environment, ITS services were offered by multiple providers (competitors), a less than reputable competitor might attempt to interfere with the services provided by another competitor, in order to gain a competitive advantage. For example, provider A might maliciously cause incorrect information to be supplied by provider B’s services, or cause provider B's services to “crash” (i.e., go down, outage). Provider A could then take advantage of the public’s outcry, to increase market penetration. For example, after recent major interruptions in AT&T long distance service, MCI ran advertisements touting the higher quality of their long distance service. While the outages in question were caused by software errors and not by malicious actions, a less scrupulous competitor than MCI could have caused the problems deliberately.

A.3 Major ITS User Services

This section will trace each of the ITS services to the possible threats that are applicable. The service definitions are from the Department of Transportation's list of ITS services.

A.3.1 Pre-Trip Travel Information

Pre-trip travel information functions can allow the tracing of vehicle or individual movements, but could also be used to influence their movement. If charged for, they could be the target of fraud.

A.3.2 En Route Driver Advisory

En route driver advisory information could be used to influence the movements of a vehicle. For example, an attacker might send a phony stop sign or reduced speed limit to lure a vehicle into an ambush, either to hijack a shipment or to kidnap an occupant. A small-town sheriff might send misleading speed limit information to lure passing motorists into a speed trap. If the driver could not prove in court that the incorrect speed limit had been electronically transmitted, then the driver might have no defense against such a trap.

A.3.3 En Route Transit Advisory

Assuming that the transit queries are made anonymously, there is little opportunity for abuse of this service. It could be used to influence traffic movements, but only in a general way.

A.3.4 Traveler Services Information

Simple queries for information do not pose security or privacy problems. However, if the traveler service includes the ability to make reservations or perform financial transactions, then the possibilities of tracking the movements of individuals or committing fraud will arise.

A.3.5 Route Guidance

Route guidance systems are subject to all threats of tracking vehicle movements and influencing traffic movements. If charged for, these services could also be the target of fraud.

A.3.6 Ride Matching And Reservation

Ride matching and reservation directly provides a trace of an individual's movements, as the purpose of this service is to allow the individual to declare a travel destination, then to arrange shared transportation. While the traveler has explicitly made known the travel destination (i.e., travel plans), the traveler still has an expectation that the destination would not be made widely available.

A.3.7 Incident Management

Incident management does not offer any particular privacy threats, as long as the data being collected on vehicle positions is kept anonymous. An attacker who could create a bogus incident might be able to divert public safety and law enforcement resources away from some other incident the attacker wished to conceal. For example, a bank robber might try to divert police attention by creating bogus accident reports through ITS.

A.3.8 Demand Management and Operations

From a security perspective, travel demand management is a combination of electronic payment services (3.10), traffic control (3.9), ride management and reservation (3.6), en-route travel advisory (3.2), and pre-trip travel information (3.1). Unique issues for travel demand management deal with the High Occupancy Vehicle (HOV) lane management, and air pollution/emission reduction. These areas could be targets of fraud, such that the operator of a vehicle might tamper with on-board devices, either to incorrectly claim HOV status or to mis-state the level of air pollution/emission.

A.3.9 Traffic Control

Traffic control services are not seriously impacted by or subjected to privacy threats, as long as vehicle surveillance is done anonymously and is limited to traffic volume, rather than individual vehicle tracking. However, there exists the potential for fraud in certain aspects of traffic control. For example, if traffic control gives priority to emergency vehicles or transit vehicles through traffic signals or lane controls, then an attacker might try to convince ITS that the attacker's vehicle was entitled to priority treatment (e.g., turning all the red lights to green on approach).

A.3.10 Electronic Payment Services

Electronic payment services for tolls, transit fares, or parking could be targets of fraud, such that the attacker either does not get charged for services, or transfers the charges to some other unsuspecting customer. Without the proper safeguards, the data storage required to implement electronic payments could reveal the customer's and/or vehicle's movements.

A.3.11 Commercial Vehicle Preclearance

There are two main threats in the commercial vehicle pre-clearance service. The most significant threat is fraud, committed by either the carrier or vehicle operator. If the data transmitted from the carrier or vehicle can be manipulated, then the operator could avoid being charged, or could operate an unsafe or overweight vehicle.

The second threat is vehicle hijacking. If hijackers purchased and installed their own sensors, duplicating those operated by the government authorities, they might be able to extract enough information from passing commercial vehicles to aid in choosing targets to hijack. They might be able to identify empty trucks from full trucks, and distinguish between classes of cargo.

A.3.12 Automated Roadside Safety Inspections

There are two potential threats associated with automated roadside safety inspections. First is the threat of fraud. There would be significant motivation for the operator of an unsafe or marginal vehicle to forge electronic "gold decals" that grant exemption from inspection, or to forge the output of specific electronic tests.

Second, there are a variety of civil and constitutional rights issues in a database containing driver status. There is a significant concern over database accuracy; this concern is justified, according to the National Crime Information Center (NCIC). There is a strong tendency to believe what the computer displays, regardless of whether it is correct. There are people that have already been stopped, detained, or even arrested, due to inaccurate information in the NCIC database. There is also a concern over who may have access to the driver status database. Specific individuals could be targeted for harassment by tampering with the database, or its contents could be used for marketing campaigns.

A.3.13 Commercial Vehicle Administrative Processes

This service consists of three sub-services: 1) electronic purchase of credentials, 2) automated mileage, fuel reporting, and fuel auditing, and 3) international border pre-clearance.

A.3.13.1 Electronic Purchase Of Credentials

The principal threat in electronic purchase of credentials is fraud. An attacker might attempt to forge electronic credentials, or cause the charges for credentials to be omitted or billed to someone else.

A.3.13.2 Automated Mileage, Fuel Reporting, And Fuel Auditing

The primary threat in automated mileage, fuel reporting, and fuel auditing is that of fraud in the fuel tax and registration reports.

A.3.13.3 International Border Pre-clearance

The most significant threats to commercial vehicle international border pre-clearance are in the administrative processes. Fraudulent electronic credentials and records could aid in smuggling, illegal immigration, or illegal drug trade. An overworked customs inspector is more likely to believe a computer than the driver of a vehicle, even though the computer may be displaying falsified information. If an electronic bill of lading were to be transmitted automatically in response to a request signal from the transponder at the customs post, a hijacker could duplicate the equipment used at the post to query the cargo of passing vehicles, in order to select targets to hit.

A.3.14 On-Board Safety Monitoring

The signals transmitted from on-board safety monitoring equipment could be used to trace vehicle movement. A vehicle operator might create fraudulent data in order to pass a safety inspection.

A.3.15 Freight Mobility Management

The signals sent from a vehicle to a dispatcher for commercial fleet management can also be used by a hijacker to trace vehicle movement.

A.3.16 Public Transportation Management

This service appears to have relatively minimal security issues.

A.3.17 Personalized Public Transit

Personalized public transit allows the tracking of individual movements. Electronic fare payments, as described earlier, offer the opportunities for fraud.

A.3.18 Emergency Notification And Personal Security

This service area has minimal adverse security issues. The ability to issue a distress call can significantly improve overall security.

A.3.19 Public Travel Security

The principal threat in public travel security is fraud against electronic payment systems.

A.3.20 Emergency Vehicle Management

The user service plan for this section was incomplete, so a complete assessment is not possible at this time. From the material available, the principal threats seem to be associated with misdirecting law enforcement vehicles, and monitoring where law enforcement vehicles will be. Both attacks could be attractive to criminals wanting to avoid the police.

A.3.21 Longitudinal Collision Avoidance

A falsified external signal could cause a vehicle to slow or stop for an ambush or actually cause a collision on a targeted vehicle.

A.3.22 Lateral Collision Avoidance

A falsified external signal could cause a vehicle to slow or stop for an ambush or actually cause a collision on a targeted vehicle.

A.3.23 Intersection Crash Warning And Control

A falsified external signal could cause a vehicle to slow or stop for an ambush or actually cause a collision on a targeted vehicle.

A.3.24 Vision Enhancement For Crash Avoidance

A falsified external signal could cause a vehicle to slow or stop for an ambush or actually cause a collision on a targeted vehicle.

A.3.25 Impairment Alert

A falsified external signal could cause a vehicle to slow or stop for an ambush or actually cause a collision on a targeted vehicle.

A.3.26 Pre-Crash Restraint Deployment

A falsified external signal could cause a vehicle to slow or stop for an ambush or actually cause a collision on a targeted vehicle.

A.3.27 Fully Automated Vehicle Operation

This service has not been well defined as yet. If vehicle automation is based solely on sensors within a vehicle, then there are few probable security or privacy threats. However, if the vehicle is controlled remotely from a centralized highway computer, then there are numerous threats relating to both tracking the movements of the vehicle and the individual. An outsider might seize control of the vehicle and deliver the passengers to a location other than their original chosen destination. This threat sounds like something from a James Bond movie, but if you accept the premise that a central highway computer can completely control a vehicle's movements, then the security threat of an attacker seizing control of a vehicle is quite simple to implement. The central highway computer would know how to drive the vehicle to a particular destination. The attacker could merely change the destination, then rely on the operational software to deliver the victim.

There are less sensational threats to fully automated vehicle operation that will depend on the details of these services as they are defined. For example, there might be fraud possibilities in the decisions of which vehicles are admitted to automated lanes, or assignment of relative priorities to different groups or types of vehicles, etc. More information on the actual design of these services will be required for a complete threat assessment.

A.4 Possible Security Countermeasures

Many of the threats described in this document can be countered with appropriate security technology that is available today. Proper application of that technology will be important to the success of the ITS architecture. Some of the threats cannot be solved by technology, because they are threats performed by authorized people acting improperly or foolishly. No system can be 100% secure. An ITS depends on people doing the right thing, but the ITS architecture can and should be designed to minimize the possibility of foolish or malicious actions of authorized personnel causing serious security and privacy problems.

It is not possible to design precise security countermeasures for ITS until the architecture's implementation is better specified. Some of the countermeasures will be dependent on the specific implementation chosen. Below, we describe only the types of countermeasures that are available to deal with the threats that have been specifically identified. Future submissions will contain much more detailed analysis of precise countermeasures.

A.4.1 Communications Security

The majority of threats to ITS come from illicit monitoring or modification of communications between the vehicle and controlling computers. These communications will probably transmit over radio links that could be intercepted by someone with the proper equipment. The correct countermeasure 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 keep up with traffic demands. If required, there are a variety of hardware encryption chips on the market that could provide increased speeds at reasonable costs.

The use of encryption technology, however, introduces some problems. First, the use of encryption will increase the development costs, because encrypted communications are more difficult to debug. Monitoring the communications to see what went wrong becomes more complex, because all communications appear to be gibberish. The use of encryption also could 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 wishes to export the equipment outside the United States or Canada would require individual export permits from the State Department. If ITS is viewed as being primarily for the United States, then export controls would not be an issue.

A.4.2 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 reliably know who has requested a particular service, and it must not be possible for the requester to deny that he made a request, when he, in fact, did. 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. Arazi [4] discusses some of the techniques for applying digital signatures to vehicular applications.

The software needed to implement digital signature protocols can be implemented on a smart card at sufficiently low cost. Each ITS user could be issued a smart card. The smart card would be inserted into a device in the vehicle to perform the necessary authentication, then charge for the services required.

A.4.3 Anonymity

Some of the possible threats associated with ITS are in tracking the location of a particular vehicle or individual. These threats can be significantly reduced if the computers do not actually store the person’s identity, or the 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, then the fare could be automatically deducted for each use. Anonymous fare cards are used today in northern California (the Bay Area Rapid Transit (BART)) and Washington, D.C. (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.

It is important to note that anonymity will not solve all of the problems of tracking vehicle or individual movements. Even if identities are not kept in a vehicle tracking system, an attacker could 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 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.

A.4.4 Computer And Database Security

Even with foolproof encryption, the use of smart cards, and anonymity, an attacker can still succeed by penetrating the security of central computers controlling ITS functions and that store the ITS databases.

The countermeasures required here are complex, and are dependent upon the precise architecture and implementations chosen for ITS, but some general principles can be discussed.

Foremost is the choice of implementation platform for the system. The computer and operating system must support an adequate level of security. Networks of PCs running MS-DOS and Windows will not meet this minimal level of security. The operating system chosen must be rated at least C2, or preferably B1 or B2 by the National Computer Security Center (NCSC) [5]. These levels of security provide both the features to control access to the programs and data, and sufficient assurance that the implementation of the security is resistant to attack.

An ITS architecture will be comprised of networks of multiple computers. There must be adequate control over the communications between these computers. Encryption will be crucial in providing both secrecy and authentication of all communications. When possible, the ITS network should not be directly connected to the Internet; the Internet could be a source of attack. Similarly, the use of dial-in lines to the ITS computers must be well controlled. This is not to say that the ITS communication architecture should not use TCP/IP protocols, but a recommendation for ITS to use a private TCP/IP network not directly accessible from the Internet.

The design of ITS software must minimize the use of highly privileged accounts. The operating system security could be nullified if the applications requiring users to be granted a high level of privilege were poorly designed . This means that security must be a requirement driving the software design and implementation. Generally speaking, it is not possible to take a large piece of software and retrofit security after the fact.

A.4.5 Regulatory And Legal Safeguards

The threats posed to any ITS architecture cannot be dealt with by technical features. The privacy issues raised by the use of ITS for law enforcement can only be resolved through regulatory and legal means. Before ITS systems are actually implemented, it is important that public debate over these issues be encouraged, so that the civil rights and law enforcement communities can express their concerns and desires. Legislation will be required to define and specify limitations on the ITS capabilities that can be used by law enforcement. The Department of Transportation should encourage public debate on these issues now. Otherwise, there could be significant public outcry, and protest against ITS when the time actually comes for implementation.

A.5 Conclusions

Security and privacy issues must be addressed in the ITS architecture if ITS is to be successful. While threats to the system are many and complex, technology exists that can deal with many of these threats. It is crucial that security and privacy safeguards be designed into the system from the start, because it is essentially impossible to add them after the fact. Security and privacy must be considered on a system-wide basis, rather than a piece-by-piece basis, because most problems will occur only when implementing the entire system. There are no technical solutions to 100% of the security and privacy threats in any system. Security and privacy can be obtained only through a combination of technical countermeasures and operational procedures. In the case of ITS, some of the operational procedures must come as a result of public debate, regulatory processes, and legal processes.

A.6 References

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