ITS Evaluation Results

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Prepared for:

Federal Highway Administration
US Department of Transportation
Washington, D. C. 20590

June 1996

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Evaluation Results Executive Summary

1.0 Introduction

Evaluation of the ITS Architecture was one of the key components of the ITS National Architecture program. Evaluation of the architecture served three purposes:

1. It lead to more informed decisions on how best to design and develop the architecture
2. It was key to developing an effective architecture that can be implemented
3. It provided key results (performance, cost, benefit, risk, etc) to use for stakeholder interaction. The evaluations were one of the primary tools for consensus building not only on the National Architecture, but on ITS services in general.

The evaluations analyzed the architecture design for three time frames: 5, 10, 20 years, and three scenarios: urban, interurban, rural. They utilized both quantitative and qualitative methods. The results of the evaluation will be reported in four categories: Communications Analysis, Cost analysis, Performance and Benefits, and Risk. These efforts form a set of independent, yet interrelated analyses which were used to assess and guide the architecture development process.

The evaluations started with the architecture, represented by the Subsystems, Functional Allocations, Market Packages, and Equipment Packages. For a summary of the architecture see the Executive Summary document. For a detailed description of the architecture see the Physical Architecture document (for a discussion of Subsystems and Equipment Packages) and the Implementation Strategy (for a discussion of Market Packages). Some evaluations are performed with regard to the architecture itself (such as risk analysis), but most of the evaluation efforts were only meaningful when a specific implementation of the architecture is specified. For example to determine a cost for Roadway Subsystem Equipment Packages one must identify precisely what infrastructure is in place and when it was deployed. To meet this need for a specific implementation to evaluate the architecture team created an Evaluatory Design, which defined the components and quantities for Each Equipment package in the architecture.

This executive summary presents the results of the evaluation efforts undertaken by the Lockheed Martin and Rockwell teams. It covers the major activities of

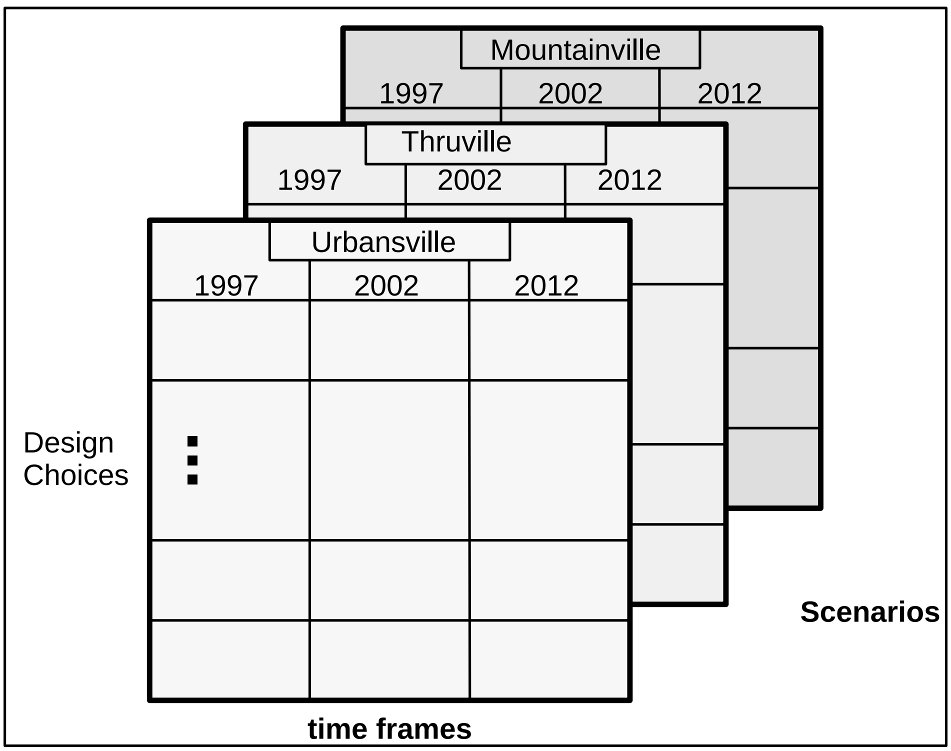
1. Evaluatory Design
2. Communications Analysis
3. Cost Analysis/ Projections
4. Performance and Benefits
5. Risk Analysis

The complete evaluation results for each of these major efforts are documented in separate deliverables for each of the above topics. This document pulls together a summary of the results from these documents. For a more complete understanding of the methodologies, analyses, and results the reader is referred to the separate volumes.

2.0 Evaluatory Design

The Evaluatory Design is not a separate analysis per se, but provided a unifying set of assumptions for the other evaluations to utilize. Many of the evaluation activities require the definition of an actual implementation in order to be performed. For example, to cost the elements of a Traffic Management function we must define how many intersections, what type of controller, and what type of communications is used between roadside and the TMC. In addition it is important that the same set of assumptions be used in all evaluations of an implementation so that true comparisons can be made (for example cost vs benefits). The Evaluatory Design captured the sets of common assumptions regarding the implementations to be evaluated.

The Evaluatory Design contains a common set of deployment assumptions for use in various evaluation efforts. The assumptions were created for three scenarios (urban, inter–urban, and rural) across three time frames (5, 10, and 20 year) as shown in the following figure. By providing one consistent set of design assumptions and decisions the different evaluation results are more meaningful.



The Evaluation Dimensions

The full document provides overviews of the key design choices made in each of these environments. These assumptions and decisions were reflected primarily in the cost and communication analyses.

The basis for the Evaluatory Design was the list of Equipment Packages provided in the Physical Architecture. An Equipment Package is a collection of hardware and/or software in a single subsystem which is used to perform some portion of a user service. For example, in the vehicle are Equipment Packages such as Route Guidance and In–Vehicle Signing. The Evaluatory Design was captured by defining specific implementations for each Equipment Package present in the scenario, and by defining the quantities of each Equipment Package. In order to define the quantities of each Equipment Package the total population for which the package is applicable was defined, and then a market penetration was developed. The multiplication of these two items provided the quantities of each Equipment Package which formed the basis for the Cost Analysis.

The first step in the definition of the Evaluatory Design was to define the applicable total population numbers. A subset of the complete table of Source Parameters is given in Table 1. These parameters define the set of potential users or uses for each equipment package.

The penetration values for each Equipment Package were developed not as a single number but as a range of values. Each Equipment Package and each time frame has a low and a high penetration value to provide the reader of the document a range of values to consider when determining the right mix of packages and services for a given situation.

The penetration values are useful for items that can be marketed to a mass audience such as commercial drivers, private vehicle owners, transit commuters, etc. In situations where an equipment package is going to be purchased and funded in small, fixed increments, such as management centers or signalized intersections, it makes more sense to adjust the parameter values over time as technology improves, funding is committed, and interest is raised. An example of the penetrations (and corresponding quantities) for a subset of the Equipment Packages(those in the vehicle) is given in Table 2. The table shows the penetrations/ quantities for the Vehicle Subsystem Equipment Packages for the Urban scenario.

The complete results of the Evaluatory Design effort are presented in the Evaluatory Design Document.

Table 1. Evaluatory Design Source Parameters

	Urbansville			Thruville			Mountainville		
Phase II Source Parameters	**5 yr**	**10 yr**	**20 yr**	**5 yr**	**10 yr**	**20 yr**	**5 yr**	**10 yr**	**20 yr**
Vehicles									
COM_Vehicles_All (Commercial Vehicles)	86,951	95,962	117,027	31,732	33,319	36,810	540	554	582
Household Vehicles	1,688,970	1,842,105	2,273,176	851,272	893,836	987,476	6,735	6,904	7,260
Transit_Vehicles_All	1,661	1,833	2,235	593	623	688	0	11	11
Emergency_Vehicles	4,444	4,850	5,981	2,128	2,319	2,562	7	7	8
Total Vehicles	1,777,582	1,939,000	2,392,439	883,597	927,778	1.024,973	7,275	7,468	7,853
Users									
Population	2,814,950	3,106,674	3,788,627	1,005,185	1,055,445	1,166,015	17,480	17,920	18,845
Transit Customers	42,980	47,440	57,850	15,350	16,120	17,810	270	270	290
Centers									
Traffic_Management_Centers	2	3	5	1	1	2	0	0	0
Emergency_Management_Centers	4	4	4	2	2	2	1	1	1
Transit Center	3	3	3	3	3	3	0	1	1
Roadway Characteristics									
Miles of Freeway	225	225	225	275	275	275	0	0	0
Miles of arterial surface streets	1,701	1,701	1,701	700	700	700	200	200	200
Ramp meters	59	59	59	0	70	70	0	0	0
Detection Sensors (Loops)	350	1,350	3,910	0	1,650	2,690	0	0	0
CCTV Basic Surveillance Cameras	150	425	850	0	410	570	0	0	0
Changeable Message Signs	59	59	59	30	60	60	0	2	2
Roadway Probe Beacons	45	75	225	0	55	92	0	25	50
In–Vehicle Signing Beacons	0	25	50	0	30	60	0	20	40
Emissions sensors	10	25	50	0	10	20	0	0	0

Table 2. Phase II Evaluatory Design:Vehicle Equipment Packages for Urbansville

Urbansville				Phase II Penetrations						Evaluatory Design Quantities Summary					
Sub-system	EP ID	Equipment Package Name	Phase II Source Parameters (Basis of Estimate)	5–yr Low	5–yr High	10–yr Low	10–yr High	20–yr Low	20–yr High	5–yr Low	5–yr High	10–yr Low	10–yr High	20–yr Low	20–yr High
VS	VS1	Basic Vehicle Reception	Total_Vehicles	1%	3%	5%	10%	25%	50%	17,776	53,327	96,995	193,990	598,110	1,196,219
VS	VS2	Driver Safety Monitoring System	Total_Vehicles	0%	0%	1%	5%	10%	25%	0	0	19,399	96,995	239,244	598,110
VS	VS3	Driver Visibility Improvement System	Total_Vehicles	0%	0%	0%	0%	1%	5%	0	0	0	0	23,924	119,622
VS	VS4	In–Vehicle Signing System	Total_Vehicles	0%	0.5%	1%	5%	10%	20%	0	8,888	19,399	96,995	239,244	478,488
VS	VS5	Interactive Vehicle Reception	Total_Vehicles	0.3%	1%	3%	10%	7%	20%	5,333	17,776	58,197	193,990	167,471	478,488
VS	VS6	Probe Vehicle Software	Total_Vehicles	0.1%	0.4%	1%	2%	2%	5%	1,778	7,110	19,399	38,798	47,849	119,622
VS	VS7	Smart Probe	Total_Vehicles	0%	0%	0%	0%	0%	0%	0	0	0	0	0	0
VS	VS8	Vehicle Intersection Collision Warning	Total_Vehicles	0%	0%	0%	0.1 %	0.5%	2%	0	0	0	1,940	11,962	47,849
VS	VS9	Vehicle Intersection Control	Total_Vehicles	0%	0%	0%	0%	1%	2%	0	0	0	0	23,924	47,849
VS	VS10	Vehicle Lateral Control	Total_Vehicles	0%	0%	0%	0%	1%	5%	0	0	0	0	23,924	119,622
VS	VS11	Vehicle Lateral Warning System	Total_Vehicles	0%	0%	0%	2%	5%	15%	0	0	0	38,798	119,622	358,866
VS	VS12	Vehicle Longitudinal Control	Total_Vehicles	0%	0%	0%	2%	5%	15%	0	0	0	38,798	119,622	358,866
VS	VS13	Vehicle Longitudinal Warning System	Total_Vehicles	0%	0.1%	5%	20%	25%	50%	0	1,778	96,995	387,980	598,110	1,196,219
VS	VS14	Vehicle Mayday I/F	Total_Vehicles	3%	5%	8%	15%	15%	30%	53,327	88,879	155,192	290,985	358,866	717,732
VS	VS15	Vehicle Pre–Crash Safety Systems	Total_Vehicles	0%	0%	0%	0%	1%	5%	0	0	0	0	23,924	119,622
VS	VS16	Vehicle Route Guidance	Total_Vehicles	0.3%	1%	2%	7%	5%	30%	5,333	17,776	38,798	135,793	119,622	717,732
VS	VS17	Vehicle Safety Monitoring System	Total_Vehicles	1%	2%	5%	20%	25%	50%	17,776	35,552	96,995	387,980	598,110	1,196,219
VS	VS18	Vehicle Systems for AHS	Total_Vehicles	0%	0%	0%	0%	0.1%	1%	0	0	0	0	2,392	23,924
VS	VS19	Vehicle Toll/Parking I/F	Total_Vehicles	1%	3%	2%	10%	10%	50%	17,776	53,327	38,798	193,990	239,244	1,196,219

3.0 Communication Analysis

The Communication AnalysisDocument contains, under the same cover, the information necessary to describe and characterize all aspects of communications within the National ITS Architecture. It presents a thorough, coherent definition of the "communication layer" of the Architecture. From a National ITS Program perspective, this encompasses two broad thrusts: 1) communication architecture definition (i.e., selection of communication service and media types to interconnect the appropriate transportation systems), and 2) several types of inter–related communication analyses to ensure the feasibility and soundness of the architectural choices made in the definition. The analyses performed comprise:

- An analysis of the data loading requirements derived from the ITS service requirements, the Logical and Physical Architectures and their data flows, the ITS service deployment timeline, and the attributes of the candidate scenarios in the Evaluatory Design.
- A wide–ranging, balanced assessment of a broad spectrum of communication technologies that are applicable to the interconnections defined in the communication layer of the Physical Architecture. The evaluation is performed from a National ITS Architecture standpoint.
- An in–depth, quantitative analysis of the real–world performance of selected technologies that are good candidates for adoption as ITS service delivery media, and for which reliable, state–of–the–art simulation tools are available. The performance is determined under the demands of the ITS and other projected applications of the media.
- A number of supporting technical and economic telecommunication analyses that address some important architecture–related issues, such as the appropriate use of dedicated short range communication (DSRC) systems, and the radio spectrum such systems would require.

3.1 Communications Architecture

In order to discuss the communications analysis efforts, a few words must be said about the communications architecture. Its definition follows, and expands upon, a rigorous, well–accepted methodology used widely in the world of telecommunications. Several wireless systems which are tied to wireline networks have used this approach. It starts from the basic network functions and building blocks and proceeds to the definition of a network reference model, which identifies the physical communication equipment (e.g., base station), to perform the required communication functions, and the interfaces between them. These interfaces are the most salient element of the model from an ITS perspective; some of these interfaces need to be standardized to ensure interoperability.

Because of the variances in the ITS user service requirements (from a communication perspective), it is clear, even from a cursory examination, that the user services do not share a common information transfer capability. Specifically, ITS user services like electronic toll collection demand communication needs that can only be met by dedicated infrastructures for technical and feasibility, notwithstanding institutional, reasons. The ITS network reference model developed incorporates this basic extension of the models developed for commercial telecommunication networks.

In general, the Communication Architecture for ITS has two components: one wireless and one wireline. All Transportation Layer entities requiring information transfer are supported by one, or both, of these components. In many cases, the communication layer appears to the ITS user (on the transportation layer) as 'communication plumbing', many details of which can, and should, remain transparent. Nevertheless, the basic telecommunication media types have critical architectural importance. The wireline portion of the network can be manifested in many different ways, most implementation dependent. The wireless portion is manifested in three basic, different ways:

- Wide–area wireless infrastructure, supporting wide–area information transfer (many data flows). For example, the direct use of existing and emerging mobile wireless systems. The wireless interface to this infrastructure is referred to as u1. It denotes a wide area wireless airlink, with one of a set of base stations providing connections to mobile or untethered users. It is typified by the current cellular telephone and data networks or the larger cells of Specialized Mobile Radio for two way communication, as well as paging and broadcast systems. A further subdivision of this interface is possible and is used here in the document: u1t denotes two–way interconnectivity; and u1b denotes one–way, broadcast–type connectivity.
- Short range wireless infrastructure for short–range information transfer (also many data flows, but limited to specific applications). This infrastructure would typically be dedicated to ITS uses. The wireless interface to this infrastructure is referred to as u2, denoting a short–range airlink used for close–proximity (less than 50–100 feet) transmissions between a mobile user and a base station, typified by transfers of vehicle identification numbers at toll booths.
- Dedicated wireless system handling high data rate, low probability of error, fairly short range, Advanced Highway Systems related (AHS–related) data flows, such as vehicle to vehicle transceiver radio systems. This wireless interface is denoted by u3. Systems in this area are still in the early research phase.

The ITS network reference model has to be tied to the specific interconnections between the transportation systems or subsystem, e.g., connection between Information Service Provider (ISP) Subsystem and a Vehicle Subsystem (VS). The key step is performed through the Architecture Interconnect Diagram (AID), actually, a whole collection of them of varying levels of detail. These marry the communication service requirements (which are generic information exchange capabilities such as messaging data) to the data flow requirements in the transportation layer, and specify the type of interface required wireless or wireline. The Level−0 AID is the top level diagram showing the types of interconnectivities between the various transportation subsystems, and, perhaps, is the best description of the communication framework in the ITS architecture. The AID Level−0 is broken down further to show subsets of it depicting the data flows that, say, use broadcast, or those that use either broadcast or two−way wide area wireless.

3.2 Technology Assessment

Various media and media types are applicable as possible candidates for each type of interconnection. The best communication technology family applicable to each data flow is specified. This still remains above the level of identifying a specific technology or system. In practice, i.e., in a real−world ITS deployment, the final step of selecting a given technology would be performed by the local ITS implementor or service provider. A proffered specification here would clearly transcend the boundaries of architecture and into the realm of system design. It is therefore avoided to the extent possible in the communication architecture definition phase.

To assist the implementors and service providers in the ITS community, a broad technology assessment was performed. It attempts to use as much factual information as is available to identify and compare key pertinent attributes of the different communication technologies from a National ITS perspective. This, at least, facilitates the identification of which technologies are suitable for the implementations of what data flows.

A host of land–mobile (i.e., cellular, SMR, paging, etc.), FM broadcast, satellite, and short range communication systems have been assessed. The assessment addresses the maturity of the candidate technologies and analyzes their capability for supporting ITS in general, and the architecture in particular. Within the limits of reliable publicly available information, the following attributes are assessed: infrastructure and/or service cost as applicable, terminal cost, coverage, and deployment time–line (if not yet deployed). Furthermore, interface issues (i.e., open versus proprietary) are also addressed from a national ITS perspective. Whenever possible analysis is performed to determine: 1) system capacity, i.e., supported information rate, 2) delay throughput, 3) mobility constraints, etc. The ITS Architecture data flow specifications are used in the analysis, including message sizes and update frequencies.

Some of the conclusions from this assessment are listed below:

A large set of architecture data flows, basically the vast majority of the u1t flows, are best supported by commercially available mobile wireless data networks, operated in the packet switching mode. Prominent among these today are CDPD, PCS, and private packet radio network systems like RAM and ARDIS.

All of these technologies have the capability to meet ITS wireless communications requirements. CDPD is promising because it may provide coverage over the entire footprint of the cellular system in a few years. CDPD's technical performance has been validated through ITS–related simulation, see below, and through operational field trials. PCS is just starting to roll out nationwide and can provide a similar performance to CDPD for ITS applications. RAM and ARDIS both have nation–wide coverage that is focused on major metropolitan areas. Although they are basically proprietary systems evidence indicates that they will perform adequately for ITS applications. Metropolitan area network (MAN) type wireless data systems intended for the non mobile user (only for fixed and pedestrian speeds), such as systems by Metricom and TAL, can be used for ITS information access, or other ITS user services if the user's mode of utilization is not mobile and the application is not time critical. Two way paging (narrow band PCS) were also assessed. These can be used to carry ITS services that are not time critical, or that do not require a real time response.

An array of satellite systems was also assessed for supporting the National ITS Architecture. These include a variety of Little (data only) and Big (voice and data) low–earth–orbit (LEO) systems, as well as more conventional medium–earth–orbit (MEO) and geosynchronous (GEO) satellite systems. Little LEO choices seem to be the most appropriate for ITS among satellite systems, since they are targeted specifically to short bursty data transactions.

As for one way wireless ITS data flows, those can be carried on one of several broadcast media. The most prominent among these are FM Subcarrier systems. A detailed quantitative assessment of the three leading high speed subcarrier systems was performed. These are the HSDS, DARC, and STIC systems, which all have roughly 7–8 kbps throughput. The analysis showed that any would be adequate to carry the broadcast data flows envisioned and incorporated into the definition of the architecture. The low speed RBDS FM subcarrier standard can also be used for the ITS data flows if the update rates are maintained low, at about once per ten minutes, again depending on the detailed implementation of the service.

One of the great advantages of the wide–area wireless interface defined in the communication layer of the National ITS Architecture, is that it relies on sharing of commercially available wireless infrastructures. Over the next several years, an explosion of such wireless infrastructures and services will be taking place. ITS will stand to benefit enormously from this powerful trend, and must leverage it to the fullest extent.

The second distinct type of infrastructure required in the ITS architecture is for dedicated short range communications (DSRC). This utilizes beacon systems, which are typically RF transponders mounted in very close proximity to the road infrastructure. Because these systems are dedicated to ITS operations, all their costs have to be absorbed by the ITS applications they support. They are adopted in the ITS Architecture for specific ITS user services whose implementation requires the close physical proximity that wide area wireless systems cannot achieve, either technically or cost−effectively. For example, they are used for toll collection, CVO credentials checks, parking lot management, and the like. The are also adopted in the architecture for applications where location specific information is needed, or available. An example of this category of use is in−vehicle signing and intersection collision warning. There are some services that could be supported by either the DSRC or wide area wireless, such as communications with fixed−route transit vehicles. For those, the architecture allows for flexibility, and local implementors would need to perform the pertinent cost tradeoffs. For some services, such as vehicle probes, the DSRC, where available for other uses, can be utilized to complement wide area wireless and wired physical sensor systems.

One of the salient conclusions of the Architecture analysis is that short range beacon systems are not recommended for use as a replacement for wide−area wireless systems. In other words, they should not be used to carry such ITS user services as route guidance, Mayday, commercial fleet management (dispatch), and so on. For a complete analysis of this issue see the Communications Analysis Document.

3.3 Performance Evaluation

Another area focus in this document is ITS communication performance evaluation. The objective is to determine whether the National ITS Architecture is feasible, from the standpoint that communication technologies exist and will continue to evolve to meet its demands, both technically and cost effectively. To set the stage for this, data loading analyses have been completed for the wide area wireless interfaces u1t, u1b, and the wireline interface w−− data loading for the u2 and u3 interfaces is not as useful, so link data rates have been determined instead.

The data loading analyses define all of the messages that flow between all of the physical subsystems. Deployment information from the evolutionary deployment strategy has been used to define which services, and therefore which messages would be available for each of the scenario and time frames specified by the Government. The three scenarios provided are addressed, namely, Urbansville (based on Detroit), Thruville (an inter−urban corridor in NJ/PA), and Mountainville (a rugged rural setting based on Lincoln County, Montana).

Seven user service groups with distinct usage patterns have been defined, along with the frequency of use of the messages by each user group. Messages have been assigned to the wireless and wireline interfaces based on suitability, and are allowed to flow over multiple interfaces with a fraction assigned to each one. The resulting data loading analyses provide the data loads on all of the above interfaces and links, and a complete description of the message statistics, which are used to drive the communications simulations.

For the wide area wireless interface, the data loading results indicate that for Urbansville in 2002 the largest data loads result from the CVO−local user service group, followed closely by transit and private vehicles. In Thruville, for the same time period, CVO–local and transit are alone the largest data users. For Urbansville in 2012, private vehicle and CVO–local are the largest data users, at about twice the rate of transit, with the others far below. For Thruville in 2012, CVO–local remains the largest data user, followed by transit. The Mountainville data loads are very low, with CVO–local the largest user, followed by private vehicles. In each of the u1t scenarios and time frames studied the forward direction data load (center to vehicle) is always higher than the reverse direction load, by a factor of two to three.

The ITS Architecture data loading results have been used as input to the communication simulations. Due to the relative scarcity of wireless communications (relative to wireline) emphasis has been placed on the evaluation of wireless system performance. However, network end–to–end performance, comprising both the wireless and wireline components, given in terms of delay and throughput was also obtained. Furthermore, representative analyses of a wireline networks have also been included.

The wireless simulations were performed using Cellular Digital Packet Data (CDPD), primarily because it is an open standard with a publicly available specification, and because validated, state–of–the–art simulations were made available for use on the ITS Architecture Program. These simulations accurately reflect the mobile system conditions experienced in the real world, including variable propagation characteristics, land use/land cover, user profiles, and interference among different system users. These modeling tools have been tested in the deployment and engineering of commercial wireless networks, for example by GTE.

Simulations have been run for the three scenarios provided by the Government. Since the number of users is very small in Mountainville, only cellular coverage was obtained to ascertain its adequacy in that remote area. For both Urbansville and Thruville, scenarios with both ITS and Non–ITS data traffic projected for the CDPD network were run, under normal peak conditions and in the presence of a major transportation incident.

The Government–provided scenario information was substantially augmented with information on actual cellular system deployment obtained directly from FCC filings. A minor amount of radio engineering was performed to fill a few gaps in the information obtained. The commercial wireless deployment assumed in the simulation runs, therefore, is very representative of the real operational systems. In fact, because of the continuous and rapid expansion of these systems, the results of the simulations are worst case in nature.

The wireless simulation results have shown that the reverse link delay (the data sent from the vehicle to the infrastructure), even in presence of non–ITS data, and in the case of an incident during the peak period, is very low (150 ms for ITS only; 300 ms for ITS plus non–ITS; with a 10% increase in the sectors affected by the incident).

The results of the CDPD simulations are further validated by the results of an operational field trial that was performed in the spring of 1995, jointly by GTE and Rockwell, in the San Francisco Bay Area. The application demonstrated was commercial fleet management, using GPS location, and CDPD as an operational commercial wireless network. A synopsis of the trial and its results are presented in an Appendix of the Communications Analysis document.

The above results for CDPD should be interpreted as a "proof by example". A commercial wireless data network is available today to meet the projected 20 year ITS requirements. Other networks also exist, and can be used, as indicated in the technology assessment sections. Future wireless data networks, and commercial wireless networks in general, will be even more capable.

The simulation results for the wireline network example deployment indicate that extremely small and completely insignificant delays are encountered, when the system is designed to be adequate for the projected use. With the capacities achievable today with fiber, whether leased or owned, wireline performance adequacy is not really an issue. The key issues there pertain to the costs of installation versus sustained operation for any given ITS deployment scenario.

The overarching conclusion from the communication system performance analyses is that commercially available wide area wireless and wireline infrastructures and services adequately meet the requirements of the ITS architecture in those areas. These systems easily meet the projected ITS data loads into the foreseeable future, and through natural market pull, their continued expansion will meet any future ITS growth. Hence, from that particular standpoint, the National ITS Architecture is indeed sound and feasible.

4.0 Cost Analysis

The goal of the cost analysis of the ITS National Architecture was twofold. First, the evaluation was to produce a high−level estimate of the expenditures associated with implementing the physical elements and the functional capabilities of ITS Services as these services are likely to be deployed utilizing the ITS National Architecture. The second goal of the cost evaluation was to provide a costing tool for ITS implementors.

The Cost Analysis developed estimates of expenditures for an Evaluatory Design implemented over three scenarios. The first scenario was a major urban area described as Urbansville. The second scenario was an inter−urban area, Thruville, and the third a rural area, Mountainville. The cost evaluations were based upon a detailed definition of sphysical element within each subsystem and an aggregation of total expenditures into initial investment (non−recurring) expenditures, as well as operation and maintenance (recurring) expenditures. Each scenario analysis covered a twenty−year deployment period.

4.1 Methodology

The basis for the Cost Analysis were the Subsystems and Equipment Packages defined by the Physical Architecture. The basic methodology of the analysis is to define a quantity and unit price for each Equipment Package. The multiplication of these gives an expenditure, which is calculated for each scenario, by timeframe. Both recurring and non−recurring expenditures are computed. The expenditures for typical area−wide deployments have limited value to implementors outside of the order of magnitude estimate for fully deployed ITS services. Therefore, a major emphasis for the Phase II evaluation, shifted to providing a costing methodology and ranges of unit prices for the various ITS services, rather than emphasizing a bottom line expenditure for the three scenarios. The Cost Analysis Document provides a detailed cost estimate for each Equipment Package in the architecture, and presents a methodology for the development of nonrecurring and recurring costs on any configuration an implementor would define. As such the actual document provides a resource guide for costing activities.

The quantities for each Equipment Package (high and low by time frame and scenario) are taken from the Evaluatory Design document. As given in this document the quantities are composed of a population times a market penetration. Rather than using a single market penetration number, a range of market penetration valueswere determined and were incorporated into the cost analysis. The basis for the market penetration range is provided in the Evaluatory Design Document.

Unit price ranges for Equipment Packages are based on available information for recently deployed ITS projects, as well as the justified unit prices developed during the architecture program by not only Rockwell and Lockheed Martin teams, but by the other teams which participated in Phase I of the architecture program.

4.2 Key Assumptions

The full set of unit prices and how to analyze them is one very key output of the analysis. However, to understand how these unit prices would aggregate for each scenario some level of summary data was created. Any effort to create summary cost numbers is highly influenced by the assumptions made in the analysis. The Evaluatory Design contains many, but not all of the assumptions used in the analysis. It contains the definition of populations (of users) and the definition of the elements (and the number of each) that are contained in each Equipment Package. For example, the Network Surveillance Equipment Package (which is in the Roadway Subsystem) has a number of detector loops which is tied to the number of intersections and the penetration estimate (what percentage of intersections are instrumented).

In addition to the Evaluatory Design quantities, there are other assumptions which have a critical impact on the summary results. For example, are communication lines between the Roadway and the Traffic Management Subsystem owned by the public agency (and hence subject to initial capital installation costs), are they leased from a private communications provider, or are the paid for on a per use basis (again from a communications provider)? On this key decision the Cost Analysis has chosen to use leased lines for all of the wireline communications (i.e. fixed communications between centers). This has the impact of lowering significantly the non−recurring costs for the public infrastructure, and increasing the recurring costs. The architecture teams recognize that each locality will make its own decision on whether to install communications or purchase the needed lines.

Another assumption which impacts the cost summaries is what elements to include as part of each ITS functionality and which to not include. The architecture teams have tried to include all new hardware, software, building space, and personnel required to provide the equipment packages. We have not included existing vehicles (e.g. for incident management) or existing functionality (e.g. call boxes).

4.3 Summary Results

Scenario expenditures for Urbansville, Thruville, and Mountainville are classified into likely stakeholder responsibility for funding. The resulting allocations for each scenario are presented below.

Urbansville High Market Penetration
Twenty Year Non−Recurring Expenditure Totals

Stakeholder	Percent of Total Funding Requirements
Government	12%
Commercial	7%
Individual	81%

Thruville High Market Penetration
Twenty Year Non−Recurring Expenditure Totals

Stakeholder	Percent of Total Funding Requirements
Government	13%
Commercial	5%
Individual	82%

Mountainville High Market Penetration
Twenty Year Non–Recurring Expenditure Totals

Stakeholder	Percent of Total Funding Requirements
Government	36%
Commercial	18%
Individual	46%

The non–recurring expenditures for the government stakeholder group are tabulated below for the deployment year milestones for the three scenarios.

Table 3. GOVERNMENT NON–RECURRING EXPENDITURES URBANSVILLE HIGH MARKET PENETRATION

Non Discounted, Five Year Summations

		Non–Recurring Expenditures		
		Yrs	Yrs	Yrs
Subsystem	Subsystem Name	1–5	6–10	11–20
CVAS	Commercial Vehicle Administration Subsystem	$379	$1	$16
CVCS	Commercial Vehicle Check Subsystem	$326	$0	$80
EMS	Emergency Management Subsystem	$406	$309	$792
EMMS	Environmental And Emissions Management Subsystem	$1	$0	$0
EVS	Emergency Vehicle Subsystem	$1,867	$4,855	$12,560
PMS	Parking Management Subsystem	$645	$920	$3,625
PS	Planning Subsystem	$0	$35	$35
RS	Roadside Subsystem	$66,969	$95,737	$224,677
RTS	Remote Traveler Subsystem	$1,600	$3,125	$12,100
TAS	Toll Administration Subsystem	$56	$10	$60
TCS	Toll Collection Subsystem	$315	$0	$168
TMS	Traffic Management Subsystem	$4,738	$5,662	$15,721
TRMS	Transit Management Subsystem	$3,089	$3,168	$270
TRVS	Transit Vehicle Subsystem	$10,220	$13,236	$29,788

Expenditures are in constant 1995 dollars in (1,000's)

Table 4. GOVERNMENT NON–RECURRING EXPENDITURES THRUVILLE HIGH MARKET PENETRATION

Non Discounted, Five Year Summations

		Non–Recurring Expenditures		
		Yrs	Yrs	Yrs
Subsystem	Subsystem Name	1–5	6–10	11–20
CVAS	Commercial Vehicle Administration Subsystem	$676	$1	$32
CVCS	Commercial Vehicle Check Subsystem	$809	$6	$202
EMS	Emergency Management Subsystem	$203	$203	$393
EMMS	Environmental And Emissions Management Subsystem	$0	$1	$0
EVS	Emergency Vehicle Subsystem	$895	$2,321	$5,380
PMS	Parking Management Subsystem	$172	$231	$905
PS	Planning Subsystem	$0	$35	$35
RS	Roadside Subsystem	$6,648	$92,638	$89,690
RTS	Remote Traveler Subsystem	$520	$1,261	$5,750
TAS	Toll Administration Subsystem	$56	$10	$60
TCS	Toll Collection Subsystem	$450	$0	$240
TMS	Traffic Management Subsystem	$2,273	$1,313	$6,110
TRMS	Transit Management Subsystem	$1,624	$3,548	$918
TRVS	Transit Vehicle Subsystem	$3,649	$4,327	$9,193

Expenditures are in constant 1995 dollars in (1,000's)

Table 5. GOVERNMENT NON–RECURRING EXPENDITURES MOUNTAINVILLE HIGH MARKET PENETRATION

Non Discounted, Five Year Summations

		Non–Recurring Expenditures		
		Yrs	Yrs	Yrs
Subsystem	Subsystem Name	1–5	6–10	11–20
CVAS	Commercial Vehicle Administration Subsystem	$338	$1	$16
CVCS	Commercial Vehicle Check Subsystem	$405	$3	$101
EMS	Emergency Management Subsystem	$203	$0	$196
EMMS	Environmental And Emissions Management Subsystem	$0	$1	$0
EVS	Emergency Vehicle Subsystem	$2	$8	$17
PMS	Parking Management Subsystem	$0	$0	$0
PS	Planning Subsystem	$0	$0	$0
RS	Roadside Subsystem	$0	$1,094	$1,572
RTS	Remote Traveler Subsystem	$0	$0	$30
TAS	Toll Administration Subsystem	$0	$0	$0
TCS	Toll Collection Subsystem	$0	$0	$0
TMS	Traffic Management Subsystem	$0	$679	$911
TRMS	Transit Management Subsystem	$0	$1,968	$85
TRVS	Transit Vehicle Subsystem	$0	$133	$137

Expenditures are in constant 1995 dollars in (1,000's)

As expected the major government expenditure item in each of the deployments is the RS, with transit systems the next largest cost items. Using the methodology, and unit prices described in this document, a public sector implementor can make their own set of assumptions and compute both recurring and non–recurring expenditures.

Tabulated below are the non–recurring and recurring expenditures for an individual user for three levels of service. Basic service provides the capability for drivers to interface with the ISP Subsystem's Basic Information Broadcast Equipment Package, receive formatted traffic advisories including accurate traveling information concerning available travel options, their availability, and congestion information in their vehicle. Basic Service also provides Vehicle MAYDAY service. Mid–range Service provides the Basic services plus In–Vehicle hardware, and software for Vehicle Route Guidance and Interactive Vehicle Reception. The comprehensive Service provides the Basic and Mid–range Services plus equipment for In–Vehicle Signing, Probe Vehicle Software, Smart Probe, and Vehicle Route Guidance.

INDIVIDUAL NON–RECURRING EXPENDITURES

Basic Service	\$450
Mid–range Service	\$1,350
Comprehensive Service	\$2,500

If all vehicle Equipment Packages including safety systems and AHS are combined, the total per vehicle non–recurring expenditure is \$8,310.

INDIVIDUAL MONTHLY RECURRING EXPENDITURES

	Operation	Maintenance
Basic Service	\$10	\$1
Mid–range Service	\$35	<\$5
Comprehensive Service	\$35	<\$8

The total monthly cost for in–vehicle ATIS services are in the range of \$0 to \$43 per month for individual users (based on average usage) and are comparable to current service cost experiences for cellular telephone service.

5.0 Final Performance and Benefits Summary

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

5.1 Technical Performance of the Architecture

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

Systems–level performance criteria:

1. *Support of ITS user services.* Does the architecture support the 29 user services across different time and geographic considerations? How well does the architecture support development and deployment of these user services?
2. *System flexibility and expandibility.* Does the architecture provide a sufficient level of flexibility to accommodate potential changes in the technology or environment associated with implementation? Will the architecture easily accommodate geographic and technical growth, as well as new user services?
3. *Performance of variously equipped vehicles.* What are the differences in system performance and benefits accruing to vehicles equipped with different levels of technology? Are these differences acceptable?
4. *Multiple levels of system functionality.* Are there various ways that the user services might be implemented? If so, can the architecture support each of these ways?
5. *Incremental installation.* Does the architecture support an evolutionary deployment? Is there a clear evolutionary path leading to the full–blown architecture? Can the architecture be tied into existing infrastructure and technologies?

Operational–level performance criteria:

1. *Accuracy of traffic prediction models.* With the architecture, how well are we able to predict traffic patterns and travel times in the network?
2. *Efficiency of traffic monitoring and control.* How well can the architecture monitor traffic conditions? What level of traffic control is possible with the architecture?

3. *Efficiency of traffic management center.* What is the information processing capability of TMCs? What level of coupling is possible among various processing functions at the TMC? How will different TMCs be coordinated?
4. *Accuracy of position location.* What is an appropriate level of accuracy in determining vehicle locations within the architecture?
5. *Effectiveness of information delivery methods.* Can information be delivered in both a timely and reliable manner?
6. *Adequacy of communication system capacity vis–a–vis expected demand.* Is there sufficient capacity in the communications system to handle the many demands that may be placed on it? How may this change for different levels of market penetration?
7. *Security safeguards.* How well is the architecture protected from accidental or deliberate breaches of security?
8. *Map update.* What are the implications of the architecture for updating maps, both in the vehicle and in the communications infrastructure?
9. *System reliability and maintainability.* How will the architecture perform under different environmental and geographic factors? How will service upgrades be incorporated in the system? What effect will infrastructure failures and environmental stress have on the architecture?
10. *System safety in degraded mode operation.* How safe is the system during degraded modes of operation? What is the likelihood of different types of system failures?

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

The analysis of the architecture's technical performance using these criteria is summarized in Table 6. This table presents a qualitative measure of the performance as well as a justification, summarizing the primary systems–level features of openness and flexibility found in the Joint Team's architecture. These systems–level descriptors of the architecture reflect an underlying philosophy that the National Architecture should retain the maximum level of flexibility so that a single specification may support deployments which will differ markedly across time and geographic regions.

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

Table 6. Summary of Systems Performance Criteria

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

Using the Evaluatory Design, the performance of the architecture was examined. The results of this analysis are shown in Table 7. Summarizing, there is sufficient existing communications, database, and other information technology to handle most communication and information processing requirements of ITS. The area of greatest uncertainty at this time involves many of the sensors and technologies associated with advanced vehicle safety and control systems.

Table 7. Summary of Operational Performance Criteria

Performance Criteria	Description
Accuracy of traffic prediction models	• Market packages support a variety of data collection methods, including cooperative probe vehicles and video (CCTV) imaging • Flexibility in design of software for traffic monitoring and prediction
Efficiency of traffic monitoring and control Efficiency of TMC	• Sufficient wireline capacity to support data collection and aggregation with minimal delay • Sufficient wireline capacity to support inter–jurisdictional and inter–agency information sharing • Sufficient in–house processing power to support real–time information processing (30 to 60 second update cycle)
Accuracy of position location	• Support for broad range of existing positioning technologies (satellite– and terrestrial–based trilateration, fixed point referencing, etc.) • Support for emerging but immature high–accuracy technologies for AVSS applications
Effectiveness of information delivery methods	• Mobile communications delays of under 0.5 s for one–way transmission using cell–based technologies • Sufficient information retrieval and database management capability to support data queries in real time (1–2 seconds) • Total information retrieval time of 3 seconds for mobile queries
Adequacy of communications system capacity vis–a–vis expected demand	• Efficient use of available cell–based communications system capacity • Non–dedicated communications channel allows more efficient use of spectrum
Security safeguards	• Support for encryption techniques for communications • Support for user authentication and non–repudiation communications overhead where anonymity is not practical • Support for technologies and messages that preserve user privacy and anonymity • Support use of TCSEC criteria for rating and securing ITS databases
Map update	• Support for map update in off–peak periods using both wireless and wireline technologies; primarily for exception updates • Data loads and cost for wireline and wireless updates are significant

Performance Criteria	Description
System reliability and maintainability	• Largely a function of system design and deployment conditions (i.e., architecture–independent)
System safety and availability in degraded modes	• Incorporation of systems ensuring data integrity and security • Support for design guidelines for improving safety in degraded mode operation • Minimal specification of architecture for high safety–critical systems that are still being defined (AVSS market packages)

5.2 Benefits of the Architecture

The basic product of the architecture is simply stated: a structure to support development of open standards. This results in derived benefits:

- **Integration**: The architecture makes integration of complex systems easier. This is achieved by presenting the structure around which standards can be developed. Because of improved integration, ITS services will benefit from better availability and sharing of traveler information such as congestion information and better utilization of shared resources such as roadside surveillance data.
- **Compatibility**: The same mobile equipment will work over the entire country. Because equipment is compatible everywhere, there is a larger total market for services resulting in more capable and cost effective products. Similarly, infrastructure systems can use standards to improve product quality and lower product costs. Future growth is enhanced by open standards being available allowing everyone a chance to participate.
- **Support for Multiple Ranges of Functionality**: Because the architecture does not dictate a design, standards can be developed to support a wide range of designs or levels of functionality in deployment providing services ranging from free to pay–for–use.
- **Synergy**: An overused concept but in this case, well suited due to the careful methodology used in development of the architecture. The methodology began with the architecture functional requirements and then mapped common requirements into specific applications. This allows the developers to recognize other applications with similar functions and thereby provide larger potential users for their products.

The benefits of Integration can be further expanded. They can be defined as the extent to which the architecture leverages integration of transportation functions, information flows and technologies. This integration is possible because the national architecture results from a comprehensive treatment of ITS user services. That is, the architecture suggests desired interfaces to achieve a comprehensive range of ITS services. The benefits of this kind of integration can be stated as follows:

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

- **Common functions and functional integration.** There are many functions within the architecture that either 1) are common to several market packages or 2) may be integrated with functions in other market packages to provide higher benefits. By sharing certain functions between market packages, cost savings and operational efficiencies may be realized by the end users of these packages. In addition, integrating particular market packages allows higher benefits to be achieved. For example, route guidance can be connected with regional traffic control. This integration allows an ISP to provide better routing advice, given that they know the arterial and freeway signal plans. In turn, if the traffic managers know how vehicles will be routed, they can better time their traffic signals to accommodate this traffic.
- **Common technology.** Data flows and functions specified in the architecture may be combined, in a specific system design, to leverage common communications and other technology. Dedicated short–range communications devices can be used both for roadside toll collection, CVO vehicle check / clearance, and vehicle probe surveillance data. A single credit or debit card technology could be used for transit fare payment, toll and parking charges, or even non–ITS purposes. Software and hardware for map databases, as well as for position referencing systems (e.g. GPS), are needed for a broad range of ITS market packages, and can leverage system standards in these areas.

As stated before, the architecture is <u>a structure to support development of open standards</u>. Such standards have the following benefits and impacts:

- **Expanded markets and lower costs.** Open interface standards may result in an expanded market for ITS products and services, with resulting price competition and lower final costs to the end user. Such an expanded market may in turn result in network externalities, where simply having more users may mean additional cost reductions or increased benefits for users (e.g. route guidance, dynamic ridesharing, or regional traffic management).
- **Compatibility.** Open interface standards also provides many technical benefits to the end user, including: portability, inter–operability, and easier data exchange between ITS applications.
- **Technology innovation.** ITS standards may impede the long–term adoption of innovative technologies surrounding a given standard. For example, wide–area wireless communication standards for ITS could be "locked in" to a certain technology before more useful or cost–effective technologies have a chance. Thus, a standard may lead to an ITS industry settling on inferior technology. However, a standard may also serve to promote rapid technology development and innovation for specific components. The net impact on technology development is not easily quantified.
- **Vendor interests.** The long–term benefits of standards to ITS product and service vendors may be very favorable. In markets such as for ITS, industry consensus standards can result in the development or expansion of the market altogether. While there may be some natural resistance to standards from some large companies with high investment in proprietary systems, there may be considerable benefits to increasing market competition among both users and vendors.

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

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

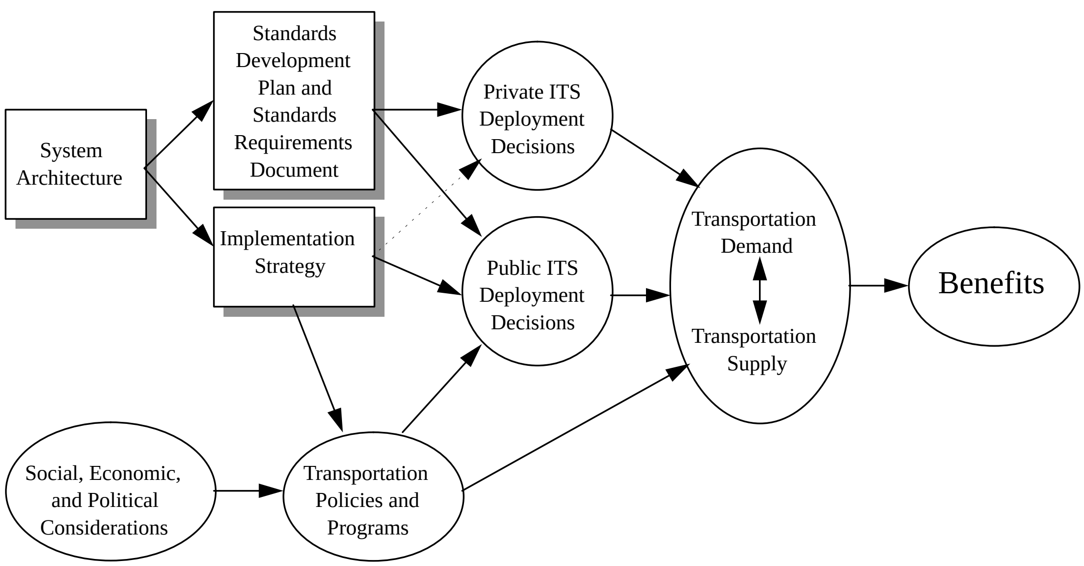


Figure 1. The Relationship of the ITS System Architecture to the Benefits

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

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

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

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

The Joint Team has also developed qualitative judgments of the benefits that can be expected for each of the market packages. These projected benefits can be aligned with specific needs of a deploying agency to select the right market packages for deployment. Table 5 associates the market packages with the identified goals of ITS and the systems architecture development. As might be expected, different goals are supported by different groups of market packages. Also evident is that several of the market packages assist in attainment of multiple goals; such market packages are likely early winners that should be promoted through early deployments.

Table 8. Benefits of market Packages for Achieving ITS System Goals

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

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

	Market Packages	ITS System Goals: Increase Tranportation System Efficiency	Improve Mobility	Reduce Fuel Consumption and Environmental Cost	Improves Safety	Increase Economic Productivity	Create an Environment for an ITS Market
CVO	Fleet Administration		***			***	**
	Freight Administration		***			***	***
	Electronic Clearance	**	***			***	**
	Electronic Clearance Enrollment					**	*
	International Border Electronic Clearance	**	***			***	**
	Weigh-In-Motion	**	***			***	**
	CVO Fleet Maintenance	*			**	**	*
	HAZMAT Management	*			**	**	*
	Roadside CVO Safety	*	**		**	**	**
	On-board CVO Safety				***	**	**
AVSS	Vehicle Safety Monitoring				***		***
	Driver Safety Monitoring				***		***
	Longitudinal Safety Warning				***		***
	Lateral Safety Warning				***		***
	Intersection Safety Warning				***		***
	Pre-Cash Restraint Deployment				***		***
	Driver Visibility Improvement				***		***
	Advanced Vehicle Longitudinal Control	**	*	***	***		***
	Advanced Vehicle Lateral Control	**	*		***		***
	Intersection Collision Avoidance				***		***
	Automated Highway System	***	***		***		***
EMS	Emergency Response	*		*	***	**	*
	Emergency Routing	*		*	***	**	*
	Mayday Support				***	*	**
ITS	ITS Planning	**	**	**	**	**	***

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

6.0 Risk Analysis

Risk analysis plays a key role in the implementation of an architecture. Early definition of the situations, processes, or events that have the potential for impeding the implementation of key elements of the ITS National Architecture is a critical element to the success of that implementation.

The focus of risk assessment for an architecture differs somewhat from that for marketing and deploying a specific product. Much more attention must be given to institutional and organizational issues that could prevent the implementation of various aspects of the architecture. On the technical side, the risk assessment must pay attention not only to the feasibility of a technology to meet the user service requirements, but also must consider the capability of multiple approaches or technologies to meet the requirements. Also, the capability for new products and technologies to be introduced over time is important to the sustained success of the overall deployment.

More detailed information concerning the risk analysis for ITS can be found in the "ITS Architecture Risk Analysis" document.

6.1 Methodology

The risk analysis used the following three step approach: Identify, Assess, and Mitigate.

Risk Identification

Identification was accomplished by a structured search for a response to the question – *What events may reasonably occur that will impede the achievement of key elements of the ITS architecture?* In addition to a word description, identification included: classification into one of the eight categories, each category being subdivided into several classification; which element of the architecture was affected; selection of one of five risk bearers; and which portion of the product life cycle was affected.

Risk Rating

Rating identifies the importance of the risk to the goals of the architecture. It comes as a response to the questions – *What is the probability that this risk will occur?* and *What is the severity of the impact on the architecture if a risk is allowed to take place?*

Rating was accomplished by estimating the probability of occurrence and severity of risk impact. Each of these two groupings was rated as either High, Moderate, or Low.

A combined, overall rating was established as the final element of risk rating. The output of this task was a listing of all risks categorized into three groups: Red risks (High), Yellow risks (Moderate), and Blue risks (Low).

Risk Mitigation

Mitigation establishes a plan which reduces or eliminates risk impact to the architecture's deployment. The question is – *What should be done, and whose responsibility it is to eliminate or minimize the effect of the risk?* Options available for mitigation are: control, avoidance, or transfer.

6.2 Identification

The identification process consisted of gathering the Red risks identified by the four architecture teams in Phase I and augmenting this list with a set of previously defined yellow risks for further analysis. Their applicability for the combined Phase II architecture was determined. This large body of completed analysis provided a good starting point. This yielded a total of 61 risks to analyze. As the program continued and the architecture has been made more complete the risks have been re−evaluated and their descriptions were updated.

6.3 Assessment

During the assessment step the combined list of risks from phase I were reassessed. This yielded a total of 10 Red risks, 36 Yellow risks, and 3 Blue risks out of the 61 risks that were analyzed. Twelve risks were combined after analyzing across the 4 teams.

A total of 10 risks have been identified and assessed as Red. Table 9 describes these risks and summarizes information on risk identification and rating. Only Operating Costs & Maintainability is not represented in the set of red risks. The risks are also evenly spread across the architectural elements: Center, In−Vehicle, Communication, and Highway Infrastructure. Of the 4 possible life cycle stages, only Production is not represented by a red risks. Half of the risks are assigned to Deployment & Sales.

Of the stakeholders that will bear these risks, the consumers bear more than the other groups. The risks are also spread fairly evenly across the three scenarios (Urban, Inter−urban, and Rural) as well as the three time frames used in the evaluation (5−years, 10−years, and 20−years from 1992).

Table 9. Red Risk Summary

Category	Classification	Description	Architecture Affected	Probability of Occurrence	Severity of Impact
Technical Feasibility	Technology Immaturity	While incorporating or adapting existing technologies, the architecture may require new or currently immature technologies (e.g.: wireless wide area data communications, vehicle guidance and control components) which may result in the use of unproved or unacceptable system components.	In vehicle	M	H
Technical Feasibility	AHS Functional Failure	Failure on an automated highway will seriously impact safety. Failure will also dramatically increase congestion on the AHS. Therefore, it will be necessary to design AHS so that systems can only fail soft, i.e., with safe reversion to manual control. This requires stringent fail safety criteria.	In vehicle	M	H
Market Acceptance	Privacy concerns	Concerns about the misuse of information related to the tracking of individual traveler Origin−Destination data, travel speeds, vehicle occupancy, etc. could impede market acceptance unless assurances are made to the public concerning data security and how data will be used and stored.	Total System	H	M
Market Acceptance	Rural Market	The rural ITS market, in areas which are not serviced by cellular telephone, needs satellite communications for MAYDAY and for traffic surveillance via Automate Road Signing Beacons, but the market size for this equipment will be small. The risk is that this may cause the cost of these products (equipment purchase plus user fees) to be too expensive to be viable.	Communications	M	H
Market Acceptance	Cost of Communications Does Not Drop	Wide area wireless data communications capabilities may not be deployed widely enough or pricing options and costs may remain too high for many ITS consumers thus market penetration will not rise as expected.	Communications	H	H

Category	Classification	Description	Architecture Affected	Probability of Occurrence	Severity of Impact
Operational Performance	Insufficient timeliness of information	Without rapid and efficient dissemination of traffic information, the end user may encounter problems that he or she purchased the system for the purpose of avoiding.	Communication	H	H
Institutional and Legal	Perceived Harmful By−Products: Safety, Environment	Adverse health, safety, and environmental impacts may be associated with the deployed systems. This may result in failure to gain the support of public and advocacy groups, (e.g. widespread use of collision avoidance radars in vehicles could cause radiation fears).	In vehicle, Highway Infrastructure, TMC	M	H
Organizational	Requires New Public & Private Partnerships	Reluctance by either the public or the private sectors could prevent deployment of TMS and ISP public−private partnerships.	TMC	H	M
Budget & Financial	Competition for Limited Capital Funds	Lack of government funds and clearly demonstrable benefits could prevent initial construction of TMS and other infrastructure by limiting the capital funds available for deployment of key architecture elements.	TMC	M	H
Budget & Financial	Decisions affected by budgetary instability	The risk to highway infrastructure improvement occurs in the O&M stage due to the lack of a steady, dependable flow of funding.	Highway Infrastructure, TMC	M	H

6.4 Mitigation

Mitigation strategies for each Red risk have been defined. These typically involve a set of actions to be taken by the sector(s) which shoulder the responsibility for the reduction of that risk. An example of the one developed for the Technical Immaturity risk of the AVSS products is given below:

TF−2.1 Technology Immaturity

Mitigation Category: Transfer
Mitigation Handler: Government, Private Producer

While the private sector will naturally develop some AVSS features such as lateral and longitudinal collision warning, they have little reason to develop other features such as intersection collision warning. Government can play a key role in speeding the development of advanced technology for safety systems.

- The government should fund testing and evaluation of Advanced Vehicle Safety Systems (AVSS) related technologies to speed maturity and deployment.
- In partnership with private producers, a government backed test and development program should include the use of an intersection grid track for operational testing.
- Employ advanced software modeling and simulation programs that address all known threatening situations.

While a lot of technology choices exist for implementing AVSS type systems, they have until recently been developed for the military. To adapt them to a commercial environment will require careful testing and integration with commercial technologies.

6.5 Summary

ITS spans a wide array of services, sectors, and users. The risks identified spread across sectors and phases of deployment. No one area stands out as an overall high risk area. The risks inherent in deployment of ITS may slow one aspect or another, but the overall effort will continue to develop and deploy.

A.0 List of Acronyms

A	
ABS	Antilock Brake System
ADA	Americans with Disabilities Act
AFD	Architecture Flow Diagram
AID	Architecture Interconnect Diagram
AHS	Automated Highway System
AMPS	Advanced Mobile Phone System
ATIS	Advanced Traveler Information System
ATM	Asynchronous Transfer Mode
ATMS	Advanced Traffic Management System
AVCS	Advanced Vehicle Control System
AVI	Automated Vehicle Identification
AVL	Automated Vehicle Location
AVO	Automated Vehicle Operation
C	
CAAA	Clean Air Act Amendment
CASE	Computer Aided Systems Engineering
CCTV	Closed Circuit TV
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CMS	Changeable Message System
COTR	Contracting Officer Technical Representative
CSP	Communication Service Provider
CVAS	Commercial Vehicle Administration Subsystem
CVCS	Commercial Vehicle Check Subsystem
CVISN	Commercial Vehicle Information Systems and Networks
CVS	Commercial Vehicle Subsystem
CVO	Commercial Vehicle Operations
D	
DAB	Digital Audio Broadcast
DD	Data Dictionary
DDE	Data Dictionary Element
DFD	Data Flow Diagram
DGPS	Differential Global Positioning System
DOD	Department of Defense
DOT	Department of Transportation
DMV	Department of Motor Vehicles
DSRC	Dedicated Short Range Communications
DTA	Dynamic Traffic Assignment

E

ECPA	Electronic Communications Privacy Act
EDI	Electronic Data Interchange
EPA	Environmental Protection Agency
EM	Emergency Management Subsystem
EMC	Emergency Management Center
EMMS	Emissions Management Subsystem
ESMR	Enhanced SMR
ETA	Expected Time of Arrival
ETTM	Electronic Toll and Traffic Management

F

FARS	Fatal Accident Reporting System
FCC	Federal Communications Commission for the U.S.
FHWA	Federal Highway Administration
FIPS	Federal Information Processing Standard
FOT	Field Operational Test
FMS	Fleet Management Subsystem
FPR	Final Program Review
FTA	Federal Transit Administration

G

GIS	Geographic Information System
GPS	Global Positioning System

H

HAR	Highway Advisory Radio
HAZMAT	HAZardous MATerial(s)
HOV	High Occupancy Vehicle
HUD	Head-Up Display

I

IEEE	Institute of Electrical and Electronics Engineers, Inc.
IVIS	In Vehicle Information System
IP	Internet Protocol
IPR	Interim Program Review
ISO	International Standards Organization
ISP	Information Service Provider
ISTEA	Intermodal Surface Transportation Efficiency Act
ITE	Institute of Transportation Engineers
ITI	Intelligent Transportation Infrastructure
ITS	Intelligent Transportation Systems
ITS AMERICA	Intelligent Transportation Society of America
IVHS	Intelligent Vehicle Highway Systems

L

LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode

LEO	Low-Earth Orbit satellite system
LPD	Liability and Property Damage
LRMP	Location Reference Messaging Protocol
LRMS	Location Reference Messaging Standard

M

MAN	Metropolitan Area Network
MAUT	Multiattribute Utility Theory
MMI	Man-Machine Interface (or Interaction)
MOE	Measure Of Effectiveness
MPO	Metropolitan Planning Organization
MPH	Miles per Hour
MTC	Metro Traffic Control

N

NA	National Architecture
NAR	National Architecture Review
NEMA	National Electrical Manufacturers Association
NHPN	National Highway Planning Network
NHTSA	National Highway Traffic Safety Administration
NII	National Information Infrastructure (aka Information Superhighway)
NTCIP	National Transportation Communications for ITS Protocol

O

OEM	Original Equipment Manufacturer
OSI	Open Systems Interconnection
OTP	Operational Test Plan

P

PCS	Personal Communications System
PDA	Personal Digital Assistant
PIAS	Personal Information Access Subsystem
PMS	Parking Management Subsystem
PS	Planning Subsystem
PSA	Precursor System Architecture
PSPEC	Process Specification
PSTN	Public Switched Telephone Network

Q

QFD	Quality Functional Deployment

R

R&D	Research and Development
RDS	Radio Data Systems
RDS-TMC	Radio Data Systems incorporating a Traffic Message Channel
RTA	Regional Transit Authority

RS	Roadway Subsystem
RTS	Remote Traveler Support Subsystem
S	
SAE	Society of Automotive Engineers
SDO	Standards Development Organization
SMR	Specialized Mobile Radio
SONET	Synchronous Optical Network
SOV	Single Occupancy Vehicle
STMF	Simple Transportation Management Framework
SQL	Standard Query Language
T	
TAS	Toll Administration Subsystem
TCS	Toll Collection Subsystem
TDM	Travel Demand Management
TDMA	Time Division Multiple Access
TIGER	Topologically Integrated Geographic Encoding & Referencing files
TMC	1. Traffic Management Center 2. Traffic Message Channel. See RDS-TMC
TMS	Traffic Management Subsystem
TRMC	Transit Management Center
TRMS	Transit Management Subsystem
TRT	Technical Review Team
TRVS	Transit Vehicle Subsystem
V	
VMS	Variable Message Sign
VRC	Vehicle/Roadside Communications
VS	Vehicle Subsystem
W	
WAN	Wide Area Network
WIM	Weigh-in Motion
WWW	World Wide Web