The US National ITS Architecture: Part 1 - Definition

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Introduction

The first part of this article presents an overview definition of the US Intelligent Transportation System (ITS) National Architecture (NA). The second part will use the Travel and Traffic Management user services to illustrate some of the operational concepts of the NA.

The NA is a *consensus* architecture, developed through an iterative process of refinement driven by regular open reviews by a broad spectrum of stakeholders. The NA thus accommodates stakeholder institutional and operational issues and concerns.

The NA is a guiding framework which will be used as input to develop ITS Standards. The NA or the resulting ITS Standards can be used by ITS system designers and integrators, product designers, and purchasers for ITS deployments that will integrate and interact to implement useful ITS services. These deployments will accrue specific benefits associated with standardized deployments in general: national interoperability; and lower costs with reduced user purchase and manufacturing risks through economies of scale and enlargement of markets. Furthermore, because the NA development was driven by stakeholder input and review, deployments based on it should be the approach that accommodates the vast majority of stakeholder concerns and issues. *Thus the NA represents an overall low risk deployment framework with regard to the institutional and operational issues and concerns of stakeholders.*

National ITS Architecture Structure

The NA specifies how logical (or functional) requirements are allocated to physical components.

The NA defines 19 physical *subsystems* that interoperate with users, the environment, and with other subsystems. The interoperations are characterized by exchange of data or information *messages*.

The NA is neutral to what technology, design, or policy is used to implement subsystems, i.e., the NA specifies requirements on subsystems (i.e., *what* they must do), not *how* they must do it. For example, a ‘‘signal coordination” process at a Traffic Management Subsystem (TMS) could give special priority to vehicles on specific roads to implement a locally determined policy (to encourage or discourage use of those roads). Furthermore, to implement the signal coordination function, the algorithm could be simple or sophisticated and the implementation technology could be manual or automatic. When signals are to be regionally coordinated, the NA defines the requirement to ‘‘coordinate signals” at a TMS as well as the definition of sensor messages (if used) from the Roadway Subsystem (RS) to the TMS, and the signal coordination messages from the TMS to the RS. The broad benefit of this scheme is that components of the NA-based deployment can be replaced, upgraded or interchanged with other NA-based components chosen locally from a national (and potentially international) market.

User Services, developed by the US DOT and ITS-America by a consensus of diverse stakeholders before NA development began, can be grouped into the following six areas: Travel and Traffic Management; Transit Operations and Management; Electronic Payment Services; Commercial Vehicle Operations; Emergency Management; and Advanced Vehicle Safety and Operations. User services are implemented in the NA through sequences of information interactions among users with subsystems and information messages among subsystems. The development of User Services continues with new user services, such as requirements for *Highway Rail Intersections* (HRI).

Functional requirements define the processing that specific subsystems do to receive and issue specific information messages. The functional requirements give the subsystems processing capabilities for current ITS deployments, and we have attempted to anticipate and include new functional capabilities which will evolve over the next 20 years.

The collection of messages between subsystems and their sequencing to implement user services represent NA interfaces, and are a crucial result of the NA program. When subsystems implement these interfaces, they will have the broad interoperability crucial to attainment of ITS benefits. Collections of related subsystem interfaces have been individually documented in 11 *Standards Requirements Packages*. These packages have been designed with input from individuals participating in ITS Standards Development Organizations (SDOs) so that they can be used as input to their consensus standards committee activities.

The functional requirements allocated to each subsystem are organized into *Equipment Packages* which represent the smallest units that can be purchased and deployed. The functions of a particular subsystem deployment are determined by the choice of included equipment packages. It is interesting to note that in the NA, a few equipment packages include functional requirements for which the technology required to implement them has not yet been developed, and many equipment packages can be expected to undergo substantial evolution as relevant technology is developed and matures. By deploying subsystems made from equipment packages that conform to the standards requirements of the NA or to consensus standards that result from the NA standards requirements, deployments will be able to upgrade to incorporate newly developed technology while minimizing impact on the rest of the ITS deployment.

The NA has identified 53 *Market Packages* which represent the deployment of specific user services with specific functional capabilities. Each market package specifies the minimum required deployment of subsystems and equipment packages for a specific capability. The relationship among subsystems, equipment packages, and market packages is shown by example in Figure 1.

Operational concepts are the collection of specific functional requirements allocated to several ITS subsystems which allow them to interoperate and effect one or more user services. The analysis and selection of competing operational concepts in the NA were guided by the following key considerations: low entry cost; provision of options in price/performance; traveler privacy (including traveler choice to trade off privacy for benefits); accommodation of increasing levels of system integration and performance; open standardization to enhance interoperability and reduce market risk; leverage existing infrastructure, making maximum use of prior investment; encouragement of private/public infrastructure cooperation; and enhancement of traveler safety (e.g. by improving emergency call responses and reducing traffic congestion).

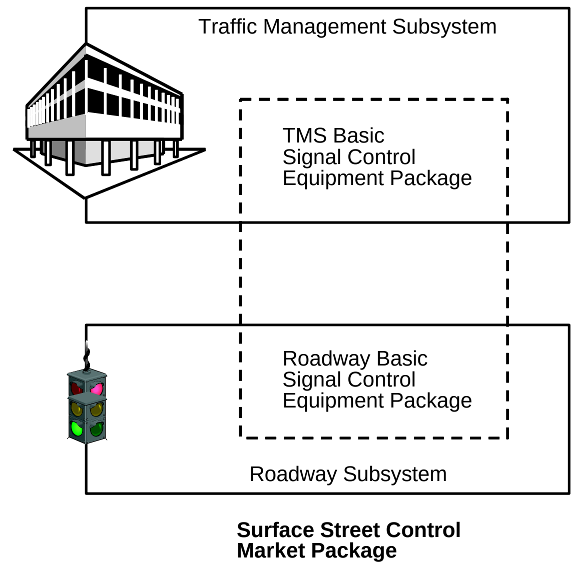

Figure 1. Example Market Package with Component Subsystems and Equipment Packages

This article will illustrate the application of these considerations in the high level definition of the NA, and as an example, in the operational concepts applied for some of the Travel and Traffic Management user services.

NA Benefits, Standards and Deployment

Individual ITS deployments yield many benefits with or without the NA: safety, economic productivity, air quality and energy consumption, mobility, transportation efficiency and reduced congestion. An NA and resultant ITS Standards, however, can assure national interoperability, lower costs and reduce user purchase and manufacturing risks through economies of scale and enlargement of markets. A further side effect of these architecture benefits is accelerated deployment. These benefits will accelerate the development of the emerging ITS industry.

The NA is being used in some early ITS standards and deployment activities. An early standard consistent with the NA is the *National Transportation Communications ITS Protocol* (NTCIP) used to define the interface between Traffic Management Subsystems and Roadway Subsystems. The NA is also being used as a basis for the *Intelligent Transportation Infrastructure* (ITI) and ITS Model Deployments. The ITI is the publicly funded infrastructure portion of ITS, and the US DOT is encouraging ITI investments to conform to the NA. As an example, the US DOT is in the process of selecting several ITS Model Deployments to partially fund Advanced Traffic and Travel Management System deployments whose designs and development will conform to the NA.

Figure 2 identifies the roadmap leading to ITS standards and deployment using the NA. Ideally, the NA Standards Requirements Packages are used by SDOs to develop consensus standards, composed of well defined inter-subsystem message interfaces with a common and comprehensive data dictionary, which are then broadly used in procurement requirements and in the development of products. The processes used to develop national and international consensus ITS standards may take years. As a result, some deployments of ITS may not be able to wait and may use the NA Standards Requirements as a basis for procurement requests and product designs.

NA Overview

With the proliferation of low cost computing and emerging ubiquitous data communications capability, distributed systems have become central to computing. These systems, such as the Internet, are successful because they economically distribute the benefits of computing for academic, business, and entertainment applications. Hardware and software executing on distributed systems may consist of many components which interact with each other in order to share data and coordinate activity. The general and long term requirements for this data sharing and coordination activity in the transportation environment include heterogeneity, scalability, security and availability. Although these requirements considerably increase the complexity of distributed systems, these issues are acknowledged and being addressed by the developers of distributed system hardware and software so that many diverse applications, including ITS, can be reliably deployed.

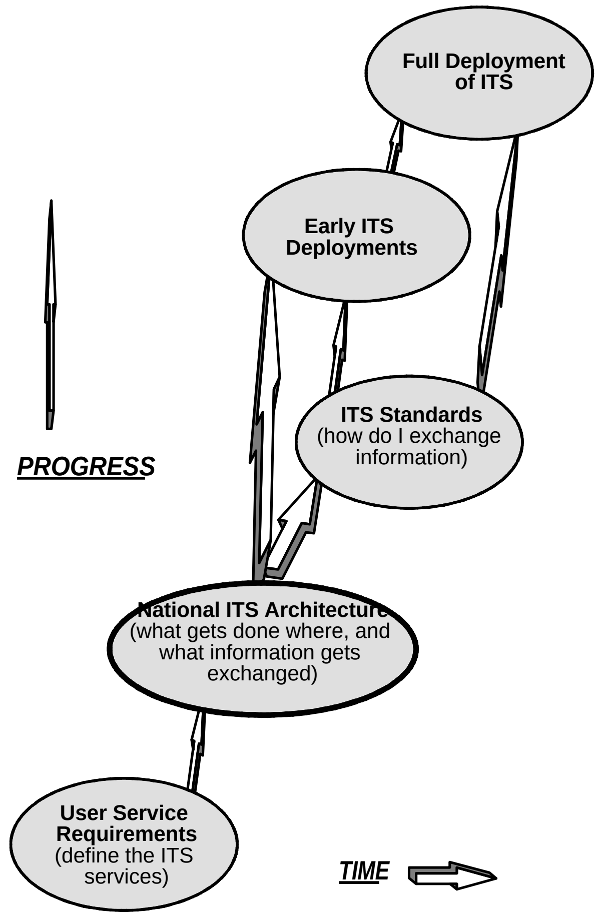

Figure 2. The NA Deployment Roadmap

Subsystems in the NA

The specific choice of nineteen subsystems in the NA is shown in Figure 3, and represents a partitioning of functions that is intended to capture all expected or likely deployment subsystem boundaries from now to the 20 year future. The resulting intersubsystem communications correspond to the full range of possible institutional boundaries.

Not shown for simplicity in Figure 3 are the message paths between subsystems and the Users, the Environment, and other Systems outside of ITS (e.g. the Weather Service).

The NA subsystems have been grouped into four classes where they share common communication elements, deployment and institutional characteristics. The following is a summary of the function of each subsystem, organized into *Center*, *Roadside*, *Vehicle* and *Remote Access* Classes.

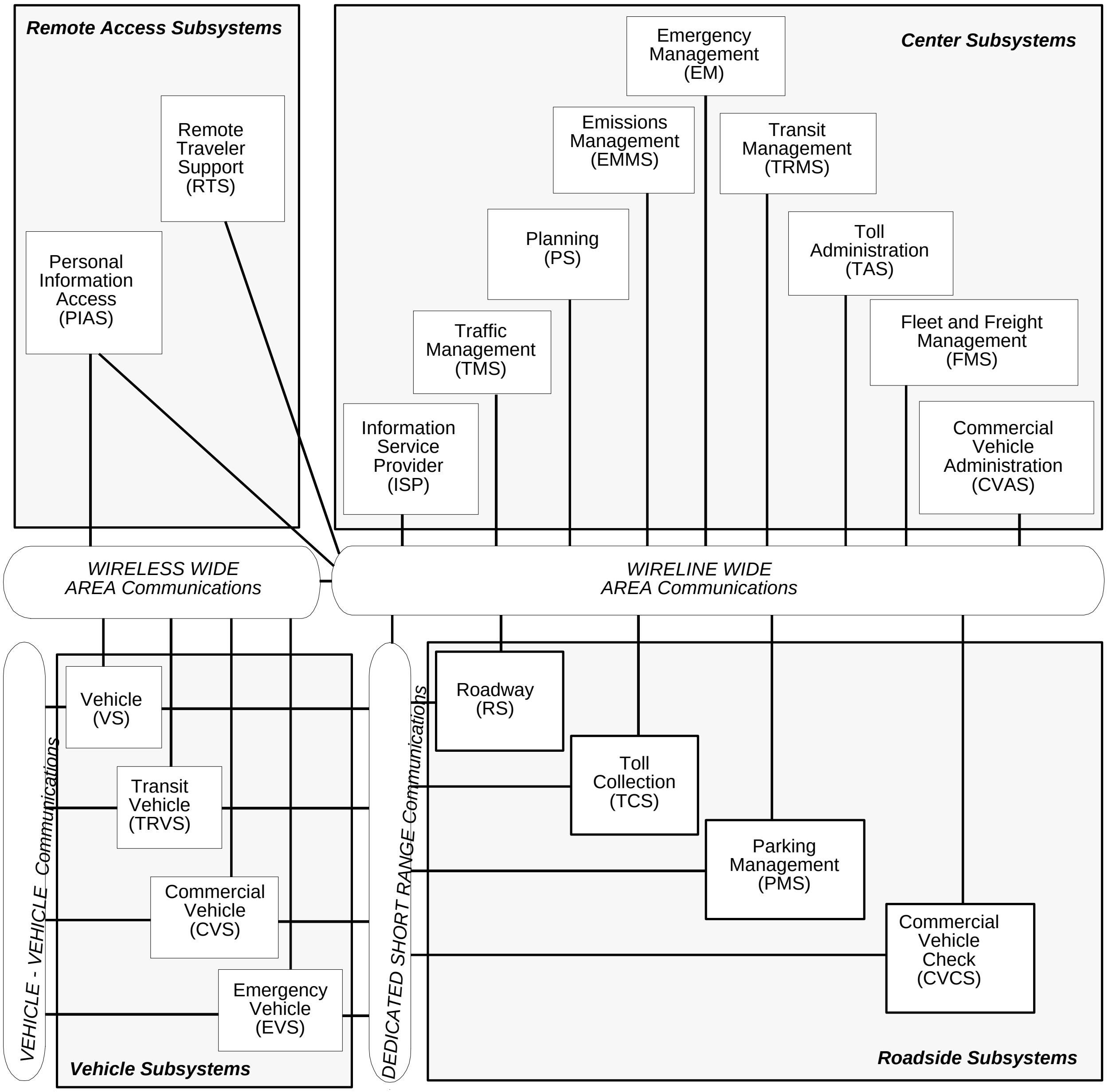

Figure 3. NA Interconnect Diagram (AID) showing Subsystems and Communication Elements

Center Subsystems

These subsystems have no requirement to be on or adjacent to a roadway and thus can be located anywhere. To communicate with other subsystems they need access to wireline communications.

1. Commercial Vehicle Administration

Sells credentials and administers taxes, keeps records of safety and credential check data, and participates in information exchange with other commercial vehicle administration subsystems and CVO Information Requestors.

2. Fleet and Freight Management

Monitors and coordinates vehicle fleet including coordination with intermodal freight depots/shippers.

Collects operational data from transit vehicles and performs strategic and tactical planning for drivers and vehicles.

3. Toll Administration

Back-end operations for Toll Administration.

4. Transit Management

Collects operational data from transit vehicles and performs strategic and tactical planning for drivers and vehicles.

5. Emergency Management

Coordinates response to incidents including hazardous materials management.

6. Emissions Management

Collects and processes pollution data and provides demand management input to Traffic Management.

7. Planning

Aids in optimal planning for ITS deployment. Collects and processes operational data from other subsystem Centers (and Parking Management) and provides results to Transportation Planners.

8. Traffic Management

Processes traffic data and provides basic traffic and incident management services through the Roadside and other subsystems. May share traffic data with Information Service Providers. Different equipment packages provide a focus on surface streets or highways or both. Can coordinate transit signal priority and emergency vehicle signal preemption.

9. Information Service Provider

May be deployed alone (to generally serve drivers and/or travelers) or be aggregated with Transit Management (to specifically benefit transit travelers), Traffic Management (to specifically benefit drivers and their passengers), Emergency Management (for emergency vehicle routing), Parking Management (for brokering parking reservations) and/or Fleet and Freight Management (for commercial vehicle routing) subsystem deployments. ISPs can collect and process transportation data from the aforementioned centers and broadcast general information products (e.g. link times) or deliver personalized information products (e.g. personalized/optimized routing) to individual information requests.

The ISP may also collect and analyze non-traveler identifying probe data from mobile clients in the process of performing dynamic route guidance. The probe data may be shared with Traffic Management subsystems.

The ISP is a key element of single mode or multimodal traveler information services such as pre-trip travel information, infrastructure based route guidance and brokering demand-responsive transit and ridematching.

Roadside Subsystems

These subsystems include functions that require convenient access to roadside locations for deployment of sensors, signals, programmable signs, or other interfaces with travelers, vehicles and freight. Roadside subsystems generally need wireline (or equivalent stationary point-to-point e.g. microwave link) communications for messages to/from one or more Center subsystems, and possibly also have dedicated short range communications to some or all vehicles passing the specific roadside subsystem deployment.

1. Roadway

Provides traffic management surveillance, signals and signage for traveler information.

2. Toll Collection

Interacts with vehicle toll tags using dedicated short range communication to collect tolls and identify violators.

3. Parking Management

Collect parking fees and manage parking lot occupancy.

4. Commercial Vehicle Check

Collects credential and safety data from vehicle tags, determines conformance to requirements, posts results to the driver (and in some safety exception cases the carrier) and records results for the Commercial Vehicle Administration Subsystem. May be located at borders to support international checking requirements.

Vehicle Subsystems

These subsystems are installed in a vehicle. The subsystems may support some combination of Dedicated Short Range Communications with the Roadside subsystems, Wireless Wide Area 2-way or 1-way communications with Center subsystems, and Vehicle-Vehicle communications.

1. Vehicle

Functions that may be common across all vehicle types are located in this subsystem (e.g. navigation, tolls) so that specific vehicle deployments may include aggregations of this subsystem with one of the following more specialized vehicle subsystems. Includes advanced vehicle safety and operations equipment packages e.g. for intersection collision avoidance and automated highway system vehicle operations.

2. Transit Vehicle

Provides operational data to the Transit Management Subsystem, receives transit network status, provides enroute traveler information to travelers and provides passenger and driver security functions.

3. Commercial Vehicle

Stores safety data, identification numbers (driver, vehicle and carrier) and last check event data. Includes in-vehicle signage for driver pass/pull-in messages.

4. Emergency Vehicle

Provides vehicle and incident status to the Emergency Management subsystem.

Remote Access Subsystems

These subsystems represent platforms for ITS functions of interest to travelers or carriers (e.g. commercial vehicle operators) in support of multimodal traveling. They may be fixed (e.g. Kiosks or home/office computers using wireline communications) or portable (e.g. a ‘‘palm-top” computer using wireless communications) and may be accessed by the public (e.g. kiosks) or by individuals (e.g. personal computers).

1. Remote Traveler Support

Kiosks for traveler information at public locations including traveler security functions. This subsystem also includes automated transit stops.

2. Personal Information Access

Home/office/portable computers for traveler information and emergency requests. This subsystem is capable of storing and using individual ‘‘profiles” for users.

Subsystem Deployment Flexibility

The subsystems shown as single entities in Figure 3 are generally representative of multiple instances of the specific subsystem. For example, several Traffic Management subsystems in a region, each with their own jurisdiction, may communicate with each other (and each with their many Roadway subsystems) to implement regional ITS policies.

Two or more different subsystems may be deployed together in ‘‘aggregations” that will reflect local needs and choices. For example, one public agency may choose to deploy a Traffic Management Subsystem (TMS) and an Information Service Provider Subsystem (ISP) together, thus taking on the role of disseminating travel information to travelers as well as managing traffic. A second public agency may choose to use the TMS-ISP message interface for the dissemination of traffic information to the public through private sector ISPs. This example also illustrates that the NA is neutral as to whether subsystems are deployed and operated by public or private entities.

Communication Elements

The ITS subsystems of Figure 3 communicate with each other using the communication elements: Wireline Wide Area Communications, Wireless Wide Area Communications, Dedicated Short Range Communications and Vehicle-Vehicle Communications.

By carefully separating the NA into transportation subsystems and communication elements, the choice of which particular communications technology is used becomes a local design decision. Communication elements become *commodities* that can be considered apart from ITS subsystems. The benefit of this separation is that the investment in ITS subsystems can be made relatively stable enabling evolution and adaptation to more rapidly evolving communication technologies.

Wide Area Communications

The NA is neutral as to whether to deploy a dedicated communication system for a particular application or to buy shared communication services. In the near term many communication elements will be dedicated, as they primarily are today (e.g. fiber systems for video traffic surveillance or SMR (Special Mobile Radio) systems for transit/commercial/emergency fleet management). As commercial data networks are deployed and mature, and the cost of access and use of these private shared data networks drops, we expect more wireline and wireless *Wide Area Network*s (WANs) for ITS to be supplied by *Communication Service Providers* (CSPs). Transitions from private data networks to commercial data networks will vary by region as it becomes practical and economical.

Interoperation of subsystems owned by different entities will be facilitated if the chosen communication network service technology uses *open* communication interfaces and furthermore is *internetworked* with other open communication services. By *open*, we mean non-proprietary interfaces that use standard communication protocols. By *internetworked*, we mean messages originating on one communication network service can be delivered to destinations on another communication network service because the two communication networks are connected. Service Providers that offer messaging access to the Internet are examples of open and internetworked WAN CSPs.

What the Internet is evolving to as acknowledged security, reliability and performance issues are being addressed has been referred to as the *National Information Infrastructure* (NII). The emergence of an NII with improved security, reliability, and performance features will be a key accelerator of ITS deployments.

Many wireline and wireless networks used for ITS may coexist in a region. Thus the Wireless and Wireline WAN Communications elements shown in Figure 3 may represent networks of interconnected networks. It is expected that the current trend toward ubiquitous internetworking of public and private data networks will continue. This will enable inter-subsystem messaging among local, regional and national ITS subsystems.

Wireline WAN Communications

The wireline data WAN communication element connects Center subsystems to Roadside, Remote Access and other Center subsystems. Internetworked with WAN wireless it may also connect Centers to Vehicles, or Centers to mobile personal computers. These elements can be ITS dedicated networks or can be privately deployed networks owned and operated by CSPs, where operators of ITS subsystems pay a service fee for connection to and use of the networks and share the network with non-ITS users.

Wireless WAN Communications

Wireless data communication systems can be: one-way (broadcast) such as FM-subcarrier or paging systems; two-way dedicated (such as for a single agency) systems such as Special Mobile Radio (SMR); or two-way shared (fee-for-service for diverse applications in addition to ITS) systems such as commercially operated networks using collections of SMR licenses (so-called E-SMR technology), data services operated by the traditional cellular telephone service providers such as Cellular Digital Packet Data (CDPD), or emerging Personal Communication Services (PCS) recently awarded spectrum licenses through FCC auctions. One-way and two-way modalities are supported in the NA for various applications. This approach allows attractive early deployments using mature and emerging low cost one-way data services (e.g. pager technology and FM subcarrier), yet also supports evolution towards more functionally rich two-way modalities.

WAN wireless communication is best suited for services that benefit from ubiquitous coverage:

- Traveler Information;
- Infrastructure assisted or infrastructure based Route Selection;
- Commercial vehicle to Fleet Management communications and
- Emergency services request.

Dedicated Short Range Communications (DSRC)

DSRC is direct wireless communication between vehicles and roadside equipment. A vehicle in motion will be in the field of a single DSRC beacon for only a brief time, thus ITS user services that use DSRC must accommodate this characteristic.

DSRC communications will be deployed where there is need for a localized exchange of data (e.g. tolling) or where the cost of the DSRC communication equipment is less than the cost of using the equivalent wireless WAN communications and where occasional rather than ubiquitous communication with the infrastructure is acceptable.

DSRC is best suited for services that can benefit from the location specific nature of each Roadside DSRC installation e.g.:

- Parking Systems;
- Toll Systems;
- Commercial Vehicle to Roadside services;
- Fixed route transit systems;
- Traffic Probes (using toll tags);
- Intersection Collision Avoidance (including Highway-Rail intersections) and
- In-vehicle signing and driver advisory.

Roadside DSRC installations that broadcast in-vehicle signage and driver advisory information messages can have a range of data sources: low cost fixed information (e.g. ‘‘STOP”); dynamic information received at the Roadside from a Traffic Management Subsystem (e.g. ‘‘Incident 2 Miles Ahead”); or dynamic information processed at the Roadside from data collected by the DSRC from passing vehicles acting as *Smart Probes* (e.g. ‘‘Icy Road Surface 4.5 Miles Ahead”).

Vehicle-Vehicle Communications

This communication element represents the direct communication path between adjacent vehicles. The deployment of this communication element will be necessary for some future Advanced Vehicle Control Systems (AVCS) services, such as high density vehicle platooning. (Vehicle-vehicle communications should not be confused with vehicle-based sensing such as used for collision avoidance, which does not involve communication between vehicles.)

Conclusions

The NA is designed to support a full range of User Services.

The NA is modularized using defined subsystems and a flexible range of communication modalities so that local regions can flexibly decide what subsets of the NA to deploy based on local priorities.

The choices made in the design of the NA were arrived at using an iterative and open process of review by a diversity of stakeholders. In this way, stakeholder operational and institutional concerns were systematically identified and addressed in subsequent revisions.

The final NA definition is being used as input to the development of ITS Standards in the US. ITS Standards consistent with the NA are the next milestone toward broad accelerated ITS deployment with NA derived benefits such as: national interoperability; and lower costs with reduced user purchase and manufacturing risks through economies of scale and enlargement of markets. As a further consequence of these NA benefits we can anticipate accelerated development of the emerging ITS industry.