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Abstract

This study explores the current development of fbnctional requirements and interface standards for the public transit industry. Recent efforts to define an information systems "architecture" for public transit have not identified the underlying need for functional requirements and interface standards, and have not identified what impacts these standards might have on both the transit industry as well as the industry vendors. To explore these issues, this research begins with a critical review of several recent architecture efforts and their resulting functional and interface requirements. Because these efforts have fallen short of a fblly-specified transit architecture, this research developed a comprehensive set of subsystems and architecture flows that more closely match the needs of public transit agencies. In addition, the research examined the possible advantages and disadvantages to the development of transit-specific interface standards. **A** survey of public transit vendors was conducted to learn about the technical characteristics of products, and about the vendor attitudes toward interface standards. The results, though not conclusive, suggest that vendors are willing to consider standards; however, the need for product customization and more comprehensive systems are important factors weighing against open interface standards. To examine the impacts for public transit agencies, four case studies of recent technology applications in the San Francisco Bay Area are described, based on their experiences with technical system design and systems integration. These case studies strongly suggest that factors such as market timing, vendor-agency communication, and "learning by doing" are key factors that affect the development of interface requirements and standards for the transit industry. The case studies also demonstrate the utility of the transit architecture developed in this research. Recommendations for practice for the California Department of Transportation are included in the report.

Keywords: public transit, advanced public transportation systems, national ITS architecture, ITS standards

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Executive Summary

Introduction

This study addresses the role of new information technologies in the public transit industry. Public transportation professionals have a need to learn about these technologies and to identify how best to plan and design these systems as they become more prevalent. Specifically, this study addresses the following questions:

- **As** best as one can tell, what can these information technologies do for transit agencies?
- Is there a way to structure how one thinks about these technologies?
- Is there a "smart" way to design and buy these systems so that they are the most cost-effective?
- What role does compatibility play in the design and purchase of these systems?

There are significant development efforts that have been recently completed or are now underway to examine these questions. The Institute of Transportation Engineers (ITE) has recently published a white paper on ITS in public transit (Wilson, 1997). More detailed, technical systems engineering efforts have been conducted through the National ITS Architecture (1996) development program, for ITS most generally, and by Sandia National Laboratories (1994), for public transit more specifically. PB Farradyne (1997a, 1997b) has also published two reports that interpret the contents of the National ITS Architecture for public transit agencies.

In addition, there are a number of efforts currently to develop interface and data format standards in the public transit industry. These include ITS-related standards from technical committee 204 of the International Standards Organization (ISO), Working Group 8 -- Public Transit. This international effort in turn is fueled by similar efforts going on within the United States, such as the Society of Automotive Engineers *(SAE)* standards 51708 and J1587 for the communications protocol on board heavy duty vehicles (including transit vehicles). Also, a national, collaborative effort for Transit Communications Interface Profiles (TCIP), was initiated in the fall of 1996. The TCIP effort is intended to develop object and message set definitions as profiles for exchanging data across various interfaces in the public transit environment.

Sensing a need for a more comprehensive approach than was possible in these studies, this report identifies a more specific "architecture" for APTS. This tool is intended to have the following benefits:

1. To provide a consistent and logical framework for assessing the technical requirements of APTS services, including: functional requirements, data needs, potential data sources, and interfaces between different technologies to identify system compatibility;

2. To provide useful guidance to transit agencies to plan for and develop their information technologies; and,

3. To provide critical raw material to the TCIP and TC204 Working Group 8 about the possible uses of the products from the national ITS architecture program.

To achieve these goals, four research tasks were conducted. First, a more detailed review of the literature was performed to determine critical functional requirements and data flows for APTS applications. From this review, a framework of functional and data requirements was established. Third, a survey of APTS and transit decision support system vendors was conducted to identify data inputs, processes, and outputs. This allows a detailed review of interface needs and potential standards requirements for current APTS-related technologies and decision support tools. Finally, the fourth task involved four case studies at transit agencies in California. For these case studies, the framework developed in earlier tasks was used to characterize the data flows, interfaces, and functions performed at each of these agencies, and specific data interface and other management issues at each case study site were identified.

The National ITS Architecture and Synthesis

The purpose of the national ITS architecture effort was to construct a comprehensive, and hence necessarily high-level, architecture that describes information flows and functions that must be performed to provide a full range of ITS services. The motivation behind a single, federally-funded national architecture is three-fold:

1. To provide a single, comprehensive architecture so that local, regional and state agencies would not have to repeat a similar development effort.

2. To identify common ITS functions and information flows, so that technologies used for some functions or information flows can also be used for other ITS functions or information flows. For the remainder of this report, this will be referred to as "technology synergy."

3. To provide a common set of definitions for information flows and functions. From this common set, local, regional, state, and national standards can be developed. Standards may help both ITS product vendors as well as ITS users (such as public transit agencies and travelers).

The national ITS architecture can be broken down into several technical components. Of most relevance to this project are the ***Physical Architecture*** and the ***Standards Development Packages.*** The full set of subsystems, the allocation of functions to those subsystems, and a summary of high-level information flows (so-called "architecture flows") between subsystems are described as the Physical Architecture. The Standards Development Plan (and Standards

Development Packages) specify what data flows occur across physical interfaces in the architecture, to help develop standards for data exchange across these interfaces. In total, it is somewhat difficult to discern the primary value of the national ITS architecture for the transit industry. However, there may be two primary areas where the national ITS architecture has value, right now, for the transit industry: (1) a more conceptual understanding of transit as an integrated part of the transportation system; and **(2)** a technical framework for developing standards for the transit industry.

Nonetheless, the national ITS architecture has several shortcomings. What is still needed is a common architecture that reflects the specific needs of the transit industry, but which maintains a somewhat obvious link to the national architecture. As a result, this research used the National ITS Architecture, and the subsystems and information flows given by the Sandia architecture, to develop a more complete physical architecture for public transit. This architecture "synthesis" defines public transit subsystems at a much higher level of resolution than is possible in the national ITS architecture, but with more "transit-external" subsystems than provided by Sandia's architecture. Also, the architecture flows from the national ITS architecture were enhanced with additional flows interpreted from the Sandia architecture.

Vendor Views on Interface Standards

To explore the state of the practice among vendors, and to explore their beliefs about interface standards for their products, a survey of 300 firms was conducted. Only 30 useful product responses were given, so there is some skepticism on the validity of the results, given such a small (approximately 9%) sample.

A short questionnaire was sent to these vendors, asking for information about their products, and the types of data formats and transfer protocols (communication rules) used as input to and/or output from their product(s). Of direct relevance to this report are the data formats and interfaces from their products. The survey asked the vendors whether they considered the interfaces from their product to be ***open*** or ***proprietary.***

Vendors were asked to describe their products in terms of whether all of the data, some of the data, or none of the data are in an open format. In about two-thirds of the on-vehicle products, there are open data formats, although several (four) of the products had no open interfaces; these included electronic fareboxes and security monitors. Much of the software for planning, management and administration, as well as more comprehensive systems that covered several product categories, have at least some open interfaces. The exceptions include accounting and financial software and proprietary communications services (paging). From these responses, it appears that one challenge to open interfaces are security-critical (financial and safety-related) services.

The survey then asked each vendor to identify benefits they received from the selected data formats, whether open or proprietary. These results are shown in Tables ES-1 and **ES-2** for open and proprietary data formats, respectively. The most common benefit identified for having open data formats is a larger market due to interfacing with other company's products. Other benefits, such as a lower probability of product obsolescence, and lower development costs, were cited less often but are still significant.

Table ES-1: Benefits of Open Data Formats

Type of Benefit	Number of Products
Larger market due to ability to interface with other company's products	17
Less chance that the product will become obsolete	10
Lower development costs related to the data formats	8
Other - Better flexibility	1
Other - Often a pre-requisite	1
Other - Easy integration with other suppliers	1
Other - Not useful to the customer	1
Other - Use of other data on bus	1

Note: Multiple answers aye possible for a given product; there were 19 product responses.

Table ES-2: Benefits of Proprietary Data Formats

Type of Benefit	Number of Products
Cheaper to produce product	7
Better revenue potential	4
Maintain product market share	8
Ability to control design	9
Product fits easily into a large system our company produces	11
Better able to tailor product to individual customer's needs	14
Other - Safety	1
Other - Performance	1

Note: Multiple answers are possible for a given product; there were 16 product responses.

The most noted reason for proprietary data formats was the ability to customize the product to meet the needs of the individual customer. Vendors also listed 11 products that benefit from proprietary standards because they fit more easily into a comprehensive system. Also, over half of the products mentioned that the control of system design was an important benefit of proprietary data formats. Fewer vendors identified cheaper production costs, better revenue potential, or market share arguments as notable benefits of proprietary data formats.

Finally, the survey also asked whether vendors (1) had been asked by transit agencies to develop open data formats and data transfer protocols, and (2) would be interested in participating materially (time and/or financially) in the development of these standards. Surprisingly, vendors report that they have only received inquiries about developing open data formats for half of the products (15 of 30). Second, for about 60% of the products (18 of 30), vendors are interested in participating in standards development.

Recent California Case Studies

Several case studies were selected to illuminate issues associated with systems integration, architecture and interface standards. Four recent projects were selected: (1) the Bay Area Transit Information Project (BATIP); (2) the Metropolitan Transportation Commission's TransLink program; (3) system integration for the OUTREACH paratransit service in Santa Clara County; and, (4) the Bay Area Rapid Transit (BART) NXTGEN project. Each of these projects has important interfaces that are described, both in terms of the proposed architecture and in terms of the potential role of standards in the technical development process.

The development of the BATIP project was aided by the existence of ***defacto*** World Wide Web interface standards such as HTTP and HTML. The existence of these established standards make the information provided by BATIP easily available to anyone who has access to the Internet. Also, both established and *defacto* data format standards such as ASCII, MS Word, spreadsheet applications, and GIF are used in transferring data to the BATIP Web site. In this way, the information provided to the BATIP developers by the transit agencies is already in well-established data formats (although not completely "open" or non-proprietary). In this case, the developers were able to recognize the potential of the World Wide Web for information dissemination, and gambled on the emerging *defacto* standards of HTTP and HTML for developing their Web information.

The TransLink project has shown both the advantages and disadvantages of standards development. Many of the information flows within the TransLink architecture are either existing or soon-to-be draft standards. It appears that the existence and emergence of these standards have certainly facilitated the progress to date in moving toward a draft specification. At the same time, the lack of existing specifications for an architecture to handle fare transactions from card readers to and through each transit agency are sticking points in the technical development. Because the existing vendors of transit electronic fare collection systems use proprietary data formats and transfer protocols, there is no open system standard or specification to date. This means that the TransLink program, in concert with the stated needs of the many transit agencies in the Bay Area, will have to develop these specifications, significantly delaying the development and release of an RFP.

In a different vein, there was a significant amount of customization and innovative technology involved in OUTREACH's SMART project. An element of "learning by doing" came in the evolution of technical system specifications where none existed before. Standards for data definitions and interfaces were, perhaps understandably, non-existent when the project began in 1993. This lack of standards meant that technical system specifications were naturally somewhat fuzzy and fluid at the beginning of the project. Moreover, it was only clear what these specifications should be after considerable working experience: it was only during more technical discussions of the emerging system that OUTREACH was able to identify and articulate specific technical needs and requirements.

Finally, in a different emphasis, the NXTGEN project at BART will replace three current computer systems which handle train control, fare collection, and station message signs individually. Under NXTGEN, all these functions will be performed on a common fault tolerant computer platform at Central Control and in each station. The main goal of NXTGEN is to combine several functions into one system, and to move from an obsolete proprietary system to an open, fault-tolerant, network-based environment. The NXTGEN architecture is an open system using open architecture standards for the fault tolerant operating systems, programming language, communications and network management protocols. The open standards architecture also enables BART to purchase off-the-shelf hardware and software. Significant cost savings and the capability for modular system expansion in the future are the main benefits expected from this new architecture.

Conclusions and Recommendations

The existing literature, the vendor survey and the case studies suggest several critical factors that affect the design and resulting benefits of functional and interface specifications.

- **A structured view of transit data flows, messages, and interface protocols is necessary.** This project has provided some insight, but a more detailed technical analysis of the functional and interface requirements is still needed.
- **It is widely believed that interface standards will be valuable to transit agencies.** While this remains an unsupported belief, it is indeed a pervasive opinion of many public decision-makers.
- **Vendors have competing interests in development of interface standards.** The common requirement for customization, and the need for product packaging, often leads to proprietary systems development. Vendors have shown interest in open interface standards, however.
- **The timing of standards development and market forces are, and must be, closely linked.** Standards should be developed in response to clear market needs. More importantly, transit standards should not be developed before sufficient need for them is demonstrated.

- Meaningful standards development requires "learning by doing." There is no good substitute for good working experience with transit data formats and system integration. Connecting with the previous point, much of the justification for standards depends on demonstrating, through working experience, that existing solutions are inadequate.

- Constructive dialog between public transit agencies and the vendors is critical.

Based on these observations, the following recommendations are made to the California Department of Transportation (Caltrans):

- **As** much as possible, Caltrans should financially support the participation of public transit agency personnel to participate in national standards development efforts, such as the TCIP.

- Caltrans should consider carefully the requests for additional funding and delay in the state's APTS-related field operational tests. Greater flexibility in funding and schedule deadlines may, in some cases, be very valuable to the process of technical innovation.

- Caltrans should provide financial support for technical evaluation **of** APTS projects in the state.

- Inasmuch as California is providing innovative technical research in APTS, Caltrans should promote these technical milestones at the national level.

- Caltrans' Office **of** Public Transportation and Transit California must promote the use of TCIP and similar standards, as they are developed, in the state-supported transit technology projects.

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1 Introduction

1.1 Nature of this Study

Information systems and technologies have altered the way many companies do business. Companies that rely on considerable amounts of data are now finding it easier to work with these data. The significant drop in the price of computer technology, and the explosion in computing power now available to the average office worker, have made computers virtually commonplace in today's business environment. Moreover, networking of computers to share files and sensitive data are rapidly being developed and installed in many businesses. Although not possible 15 or 20 years ago, now one can easily take many communications and information technologies for granted: technologies such as fiber optic cable, wireless paging and cellular phone services, the Internet and the World Wide Web.

The transportation industry is no exception to this trend. Many public transportation agencies have World Wide Web sites where one can examine transit maps, routes and schedules, current traffic conditions, and many other types of transportation information. Transportation agencies are putting in computer networks to link different departments to allow data sharing and electronic communication. In many agencies, desktop computers are used in many different departments, across many different functions. There is also likely to be continued growth in the field of computers and information technology for the foreseeable future, at least the next 5 to 10 years.

This larger trend in business has not been without its technical challenges. Proprietary or otherwise incompatible software and hardware has often surfaced, at considerable cost to replace or upgrade such material. Software written for one purpose may not be compatible with other software written for a different purpose. As an example, software written to develop transit schedules and routes is not often compatible with existing geographic information systems (GIS), which could be used to map and analyze transit service patterns and ridership trends. In a similar way, computers and other hardware are not compatible. Data collected in most electronic fareboxes in the public transit industry can only be read by proprietary devices. Transit radio systems are not compatible, making it very costly to upgrade or replace existing standard or trunked radio systems.

These compatibility problems have several implications as the use of information technologies grows in the future. First, it may be very costly to repair, upgrade, and/or replace software and hardware that does not allow "plug and play" compatibility. Components will remain expensive, and components from different software and hardware vendors may not work together. For public agencies that are increasingly cost-conscious, this lack of compatibility is very expensive: it means frequent upgrading of systems and higher costs for proprietary systems. In the public transit industry, radio systems and fareboxes are expensive systems to replace, and often an agency has little or no choice of vendors to upgrade or replace these systems.

Second, the compatibility of software and hardware also may turn out to be a real stumbling block to the growth of the market of these new technologies. Technologies that have not developed such open, ubiquitous and common means of sharing data have lost market share or have dropped out of the market altogether. Examples include proprietary signpost (beacon) positioning systems, transit-only magnetic stripe cards, and proprietary telephone-based traveler information systems. On the other hand, the explosive success of the Web for sharing transportation information is based on a common form of communication and data formats for information sharing on the Internet. The public release of the global positioning system (GPS) to determine physical locations has resulted in a significant drop in the price and in widespread availability of GPS devices. Paging and cellular telephone services have also grown significantly once these services had open formats and relatively ubiquitous coverage areas.

With this in mind, this study addresses the role of these information technologies in the public transit industry. Under the premise that these technologies are going to grow and expand over the next 10 to 20 years, public transportation professionals have a need to learn about these information technologies and identify how best to plan and design these systems as they become more prevalent. Specifically, this study addresses the following set of questions:

- As best as one can tell, what can these information technologies do for transit agencies?
- Is there a way to structure how one thinks about these technologies?
- Is there a "smart" way to design and buy these systems so that they are the most cost-effective?
- What role does compatibility play in the design and purchase of these systems?

At the outset, it should be understood by the reader that the answers to these questions are not at all obvious. Some may tout information technologies, and associated standards, as things that will "revolutionize" the way one think about the transportation system, and perhaps they will be proven correct, in time. However, this report presents a somewhat critical review of these questions, and does not presume *apriori* that the generic area of "information technologies" will definitely provide a panacea for many problems and concerns of the public transit industry.

To answer these questions, this report is framed within the rubric of "intelligent transportation systems," or ITS. Within the public transportation field, the current nomenclature is "advanced public transportation systems," or APTS.[1] This framework is adopted primarily because there has been a considerable amount of research, development, and application under the ITS and APTS umbrella over the past 5-10 years. This foundation of material represents some of the most useful and insightful evidence of the role of information systems and technologies for transportation planning and operations.

1.2 Review of Current Efforts

There are significant efforts that have been recently completed or are now underway to examine how public transportation agencies can take advantage of existing information technologies. The following discussion identifies and briefly summarizes the most salient efforts at the present time. A more exhaustive review of the literature in transit information systems and technology appears in a previous PATH report, Hickman and Day (1996).

The Institute of Transportation Engineers (ITE) has recently published a white paper on ITS in public transit (Wilson, 1997). This white paper addresses common questions that public transit agencies may have about many of these information technologies. It addresses the vision

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[1] The authors are concerned that terminology should not stand in the way of clarity. For the purposes of this report, the term ITS is used to indicate the use of any of the more recent developments in hardware, software, and communications systems in the transportation field. ITS as a term, though, is a recent acronym that simply represents a process that has been going on for at least 25-30 years, as long as computers and information technologies have found applications in transportation. Similarly, the term APTS is only a recent acronym that represents applications that have been going on in the transit industry for at least 30 years.

of both the United States Department of Transportation (USDOT) and that of many transit industry leaders about the possible role of these new information technologies. Also, the paper includes largely non-technical introductions to many of these technologies that have already been applied in the industry: so-called “smart cards,” a communications bus on transit vehicles (“bus on a bus”), wide-area wireless communications, traveler information systems, and map and spatial data bases. In addition, several contributions to the white paper identify benefits of these technologies that have already been realized at many agencies in the U.S.

A more technical study of information technologies and their role in transportation was conducted through the Federal Highway Administration of the USDOT. From 1993 to 1996, the USDOT has been sponsoring the National ITS Architecture development program. The objectives of this research effort were to determine many of the technical requirements for “successful” implementation of these new technologies. Using system engineering methods, the architecture contractors were tasked to provide an “architecture” for ITS. This architecture primarily provides a consistent and (so far) relatively universal set of data flows, functional requirements, functional allocation to physical subsystems, and recommendations for necessary interface standards. Because it covers a broad range of potential ITS services and applications, the national architecture is necessarily too broad to be considered for a specific plan or design. Rather, the architecture provides a flexible and open framework from which many different types of information technologies can be integrated. To date, the documentation from the national program is useful primarily as both a high-level framework for ITS, and as a technically detailed blueprint for developing local plans and information system designs.

A more specific architecture relating to public transit applications was developed by Sandia

National Laboratories (1994). This architecture development was sponsored by the Federal Transit Administration (FTA), and was intended to highlight the specific needs of public transit within the FHWA's broad national architecture program. Again, this document is largely a technical description of functions and information flows that are possible in considering current technologies in the transit industry. While the Sandia architecture developed specific functional areas and communication needs for transit, the architecture did not provide a detailed functional analysis of different transit subsystems, nor did it identify specific data flows and interface requirements between these units. Also, the set of documentation from Sandia is difficult both to read and to interpret.

In reaction to the seemingly endless and often confusing documentation from the national ITS architecture program, the USDOT has also recently commissioned a set of reports to identify the possible uses of this architecture by the public transit community. These reports, produced by PB Farradyne Inc., include an executive summary of the value of ITS for the transit community (PB Farradyne, 1997a). This short (10-page) report documents many of the uses and possible benefits of information technologies in the public transit industry. A second volume, an extensive technical report (PB Farradyne, 1997b), provides a "Reader's Digest" version of the architecture. It explains in more simple language what the architecture is intended to do, and how one might use the national documentation to plan and design a transit-oriented ITS systems architecture. As it stands, this technical document does not contain specific details of the architecture per se; rather, it provides a nice reference to guide the reader through the wealth of material produced by the national ITS architecture program.

Finally, one might also mention a number of efforts to develop interface and data format standards in the public transit industry. Several national and international efforts are now underway. On the international scale, the public transit industry as a whole is involved in a set of standards with the International Standards Organization (ISO). Technical committee 204 of ISO is charged with developing a set of international standards for various ITS applications. Working Group 8 of this technical committee is charged with developing a set of international standards that relate to ITS services for the public transit community. This working group met for the first time in May 1996 to define areas of need for standards. Three areas have been identified already: (1) communications between on-board electronic devices, (2) dynamic data transfers, and (3) common data base definitions and standards for data integration.

This international effort in turn is fueled by similar efforts going on within the United States. In the area of vehicle communications, the Society of Automotive Engineers (SAE) has published a set of industry standards, J1708 and 51587, for the communications protocol on board heavy duty vehicles (including transit vehicles). This set of standards, introduced in October 1993, are claimed to be the first ITS standards in the United States. In addition, the areas of dynamic data transfers and data integration have been fueled by other national efforts. For the past several years, the Map and Spatial Databases Working Group of the APTS Committee of ITS America has identified needs of the public transit community for a set of standard spatial data base definitions (ITS America, 1994). This working group is now examining a potential transfer standard for these data. Also, there is a similar effort on the part of many transportation engineers to develop a common communications protocol for ITS purposes. This falls generally under the auspices of the National Transportation Communications for ITS Protocol (NTCIP). A parallel and collaborative effort for a set of transit standards, the so-called Transit Communications Interface Profiles (TCIP), was initiated in the spring of 1996. The TCIP effort is intended to develop object and message set definitions as profiles for exchanging data across various interfaces in the public transit environment.

1.3 Objectives of this Study

As evidenced above, there has been considerable interest over the past several years in research, development, and analysis of various information technologies and their interfaces. More technically, this work has focussed on so-called "functional requirements" and data (or information) flows necessary to support various hardware, software, and communications associated with ITS and with APTS. However, in our assessment, most of these "system architecture" efforts on a national scale have not yet gone into sufficient detail to help transit agencies determine what is involved in adopting these new information technologies. The national ITS architecture documentation is too broad to sufficiently describe and enhance existing information technologies or decision support tools with the transit industry more specifically. This reflects a necessarily broad focus for the national transportation system. Nonetheless, it is our belief that there is some good system engineering principles and results from the national ITS architecture program (1996), and from the Sandia effort (1994) that went to support it.

On the other hand, other efforts to define functions and interfaces for information systems and technologies is still very preliminary. Many of the recent-completed efforts (e.g. by Sandia) and the current efforts in the TCIP and TC204 Working Group 8 have, to date, not made enough progress to help transit agencies in defining their needs or in determining the requirements of their information systems and technologies. It seems we are still at the beginning in defining functional and interface requirements to meet the specific needs of public transit.

Sadly, the authors also fear that the work of the TCIP and TC204 Working Group **8** may not make the most effective use of the work of Sandia (1994) and the national ITS architecture program (1996). Moreover, the transit community seems to be searching for more structure in determining the possible value of APTS services and the technical requirements to use these technologies. This is most explicitly evidenced in the more cursory work of PB Farradyne (1997a and 1997b).

Sensing this need, this research project (and this resulting report) is intended to identify **a** more specific "architecture" for APTS. More specifically, it works with the existing work of the national ITS architecture program, and the Sandia transit information diagrams, to develop a consistent yet practical technical framework for public transit information systems. This tool is intended to have the following benefits:

1. To provide a consistent and logical framework for assessing the technical requirements of APTS services, including: functional requirements, data needs, potential data sources, and interfaces between different technologies to identify system compatibility;

2. To provide useful guidance to transit agencies to plan for and develop their information technologies; and,

3. To provide critical raw material to the TCIP and TC204 Working Group **8** about the possible uses of the products from the national ITS architecture program.

To achieve these goals, four research tasks were conducted. First, a more detailed review of the literature was performed to determine critical functional requirements and data flows for APTS applications (as highlighted above in Section 1.2). From this review, a framework of functional and data requirements was established. Third, a survey of APTS and transit decision support system vendors was conducted to identify data inputs, processes, and outputs. This allows a detailed review of interface needs and potential standards requirements for current APTS-related technologies and decision support tools. Finally, the fourth task involved four case studies at transit agencies in California. For these case studies, the framework developed in earlier tasks is used to characterize the data flows, interfaces, and functions performed at each of these agencies, and specific data interface and other management issues at each case study site will be identified. This allows the development of recommendations about how a specific transit agency might consider integrating APTS technologies into their existing systems. With these case studies, one may identify how this "architecture" framework may be applied at representative agencies, and what technical issues may surface at those agencies that can enhance or hinder the use of new information technologies.

With this in mind, this report is organized as follows. Chapter **2** reviews the existing literature surrounding the national ITS architecture development program. This literature review highlights the results of these various studies and their contribution in developing a more structured APTS "architecture." **A** more direct synthesis of this material is provided in Chapter **3,** where a consistent framework for APTS services and technical systems is defined. The material from the national ITS architecture is used to develop a transit-specific framework of subsystems, functional requirements, and information flows. Chapter 4 highlights a survey of APTS vendors to determine technical requirements of various software, hardware, and communications systems. It also summarizes their thoughts on industry standards for APTS products. To make this framework practical, Chapter 5 summarizes four case study transit agencies. The "framework" from Chapter 3, supported by the vendor survey in Chapter **4,** are used to identify specific technical capabilities and needs at several transit agencies in California.

These are meant to demonstrate the need for and value of the architecture framework. Finally, Chapter ***6*** presents overall conclusions from this research, and makes specific recommendations for the State of California and for the APTS program nationally.

2 Making Sense of the National ITS Architecture

This chapter describes the national intelligent transportation systems (ITS) architecture. Limited exposure to the national architecture program can leave one with the feeling that there is much more to the architecture than initially meets the eye. With a set of 12 documents totaling approximately 5340 pages, the architecture reports fail miserably to help the average reader to digest the architecture quickly and easily. **A** recent effort by PB Farradyne (1997b) attempts a short synopsis and "roadmap" to the architecture for the transit community.

While not intending to duplicate that effort, it is essentially the intent of this chapter to explain the transit elements of the architecture in the clearest and most concise manner. More directly, it provides some insight into what the national architecture is and what benefit it may have for the public transit industry. The last part of the section goes into greater depth about the elements of the national architecture that are relevant to the transit industry.

2.1 What is the National ITS Architecture?

2.1.1 Nature and Intent

Fundamentally, an "architecture" is a systems engineering term to describe the combination of functions and data flows necessary to achieve the goals of a particular system. The architecture describes what functions must be performed, and what information is necessary to perform those functions, to meet certain objectives. The net product of the architecture is, in its essence, a set of data flows and functions from which a more detailed system design can be developed.

The following formal description was developed by ITS America (1994, p. 6):

> "A system architecture is the framework that describes how system components interact and work together to achieve total system goals. It describes the system operation, what each component of the system does and what information is exchanged among the components.... A system architecture is different from a system design. Within the framework of an architecture, many different designs can be implemented."

As suggested in this definition, the architecture is not a system design, but simply a framework that allows public agencies and private companies and travelers to design ITS systems that can achieve ITS goals. For any metropolitan area, or transportation agency, the architecture sets out a framework of information flows and functions. These in turn provide the initial "raw material" to guide public agencies in developing and designing information systems and technologies.

More generally, the purpose of the national ITS architecture effort was to construct a comprehensive, and hence necessarily high-level, architecture that describes information flows and functions that must be performed to provide a full range of ITS services. The motivation behind a single, federally-funded national architecture is three-fold:

1. To provide a single, comprehensive architecture so that local, regional and state agencies would not have to repeat a similar development effort.

2. To identify common ITS functions and information flows, so that technologies used for some functions or information flows can also be used for other ITS functions or information flows. For the remainder of this report, this will be referred to as "technology synergy."

3. To provide a common set of definitions for information flows and functions. From this common set, local, regional state, and national standards can be developed. Standards may help both ITS product vendors as well as ITS users (such as public transit agencies and travelers).

2.1.2 Basics of Architecture Development

The national ITS architecture was developed as part of a program sponsored by the Federal Highway Administration (FHWA), beginning in the fall of 1993 and continuing through to July

1996, with some small follow-up activities still underway. The genesis of the program was based on a joint committee convened with representatives of the FHWA and the Intelligent Transportation Society of America (ITS America). Out of this committee came the motivation for the architecture, articulated above, and a request for information about a set of "user services" that describe what system goals ITS is intended to achieve.

As it has evolved, the realm of ITS was seen as encompassing a set of 27 (now up to 30) user services. These services were codified into a set of "user service requirements" (USDOT, 1993), describing a set of "functional requirements" for each of the ITS user services. That is, they specified what functions must be performed to achieve *all* functions of ITS. These functional requirements are the primary inputs to the architecture development process.

More specifically, the national architecture has emerged from the following development process. First, a "logical architecture" is developed that includes simple ITS functions and most elementary data that is necessary to complete each function. Second, **a** "physical architecture" takes the basic framework of the logical architecture and translates it into physical objects and communications links. Third, this physical architecture is translated into several different products to describe how ITS user services may work, and how the architecture can be used to develop ITS-related standards. These steps are described more completely in the following paragraphs, and is illustrated in Figure 2-1.

To begin, the functions listed in the user service requirements are decomposed into elementary functions, called *process specifications* (or P-Specs). P-Specs are described at a suitable level of detail and are typically fairly simple statements, such as "record fare payment" or "compute traveler itinerary." In addition, data necessary to complete each P-Spec are also identified. In the example of "record fare payment," data such as a traveler ID number, fare type,

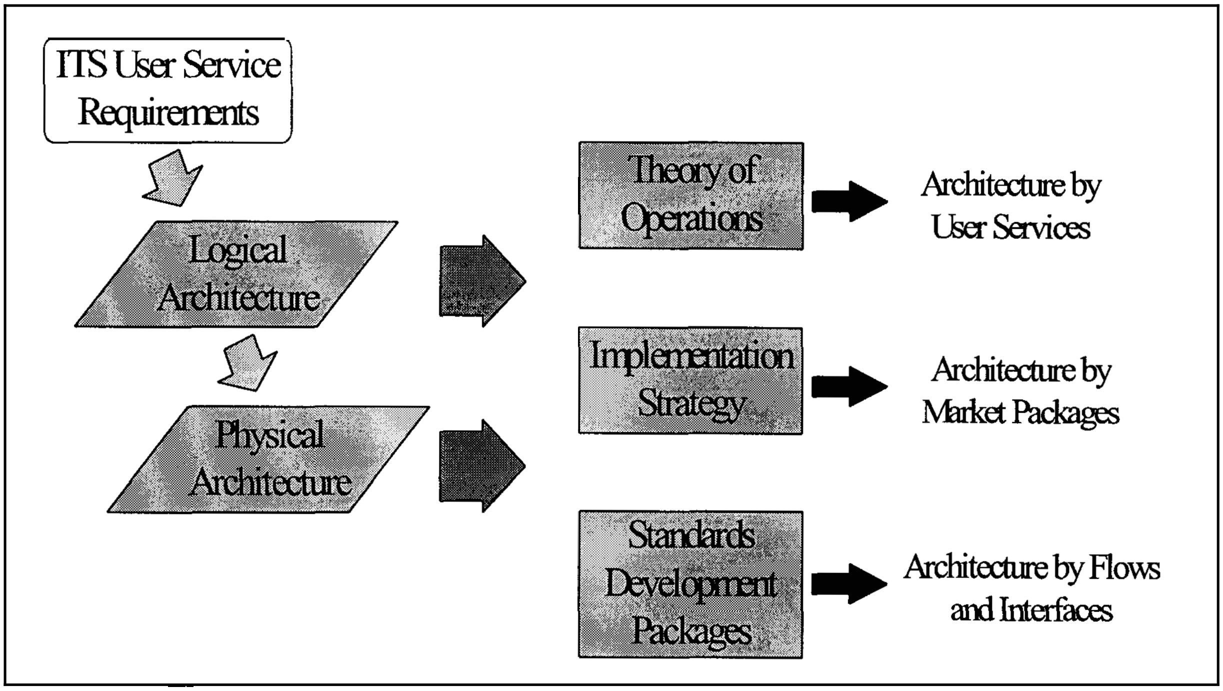

Figure 2-1: National Architecture Development Process and Products

amount of fare, etc. may be necessary to complete the function. The use of data is traced from P-Spec to P-Spec, thus identifying (i) for what functions the data are used, (ii) what the sequence of functions is, and (iii) how data may flow from one function to another. This yields what we call "data flows" connecting one P-Spec to another. A comprehensive list of P-Specs and data flows together comprise what is known as the ***Logical Architecture*** (National Architecture Program, 1996).

The logical architecture is still a very abstract construct. To make it slightly more tangible, a set of "subsystems", describing real-world physical objects that are related to ITS, are created. Within the architecture, these include four classes of subsystems: vehicles, centers (i.e. management centers), roadway (or wayside) systems, and personal access subsystems (e.g. a kiosk or a cellular phone). The P-Specs from the Logical Architecture are then "allocated" to one or more of the subsystems. **As** an example, "record fare payment" might be allocated to (some device on) the transit vehicle, while "compute traveler itinerary" may be allocated to (software in) a kiosk or an information center. Throughout this allocation, the integrity of data flows between P-Specs is maintained. That is, suppose a data flow connects P-Specs **A** and B. If **A** and B are within the same subsystem, the data flow is also contained totally within the subsystem. However, if **A** and B are in different subsystems, then the data flow between **A** and B crosses a physical boundary (e.g., air between the transit vehicle and the transit management center).

The data flows that cross a physical boundary are aggregated into what are called *architectureflows.* **As** an example, some data passing from the transit vehicle to the transit operations center could be aggregated into an architecture flow called "transit vehicle condition info." The architecture flows thus describe a set of data that must pass between two distinct subsystems. The full set of subsystems, the allocation of functions, and a summary of architecture flows between subsystems are described as the ***Physical Architecture.***

The physical architecture, however, does not clearly articulate how services are performed - it simply dictates the wide range of subsystems and architecture flows. To describe how services are performed in the architecture, two additional means are provided. First, the ***Theory of Operations*** describes how information flows within the architecture to perform a particular user service. It traces information flows from one subsystem to another, and describes what functions are performed within each subsystem, to achieve the **full** functionality of a user service. An example might be the user service "Pre-Trip Traveler Information," which includes a request from a traveler, collection and processing of real-time traveler information, and presentation of that information back to the traveler. For such a basic description of how the architecture works, the *Theory of Operations* provides a very readable and user-friendly introduction to the full national architecture.

A second form of the physical architecture is the display as *marketpackages,* as described in the ***Implementation Strategy*** document. The idea of a market package concept is to re-configure many of the user services into "bundles" that more closely match (i) the available technologies and how these will evolve over time, and (ii) the growth of ITS markets and services over time. In this way, the market packages present something that a public agency might consider buying to achieve some (but perhaps not all) levels of ITS functionality. Using the example of "Pre-Trip Traveler Information," the display of static traffic and information may be one *marketpackage* that is currently available, e.g. via kiosks or the World Wide Web. Collecting and processing real-time information, on the other hand, may involve a higher level of technical capability than is currently available, and thus would be part of a different market package.

The final form of the physical architecture that has relevance to this project is the ***Standards Development Plan.*** The idea here is to specify what data flows occur across physical interfaces in the architecture, and to help develop standards for data formats or for data exchange across these interfaces. The architecture program produced a set of documents (called ***Standards Development Packages)*** that re-package the architecture flows from the physical architecture, and the P-Specs and data flows from the logical architecture. Essentially, these architecture flows and data flows provide raw material to standards development organizations (SDO's) to specify data flows in the *applications layer* of a standard. The SDO's thus can use this information to help develop interface standards or common data formats.

2.2 What is in the National Architecture for Transit?

In total, it is somewhat difficult to discern the primary value of the national ITS architecture for the transit industry. In its current form, the national architecture does not give much direction for individual agencies to design and implement ITS technologies. Instead, the architecture delivers a very broad, flexible framework from which many possible designs are possible. This makes it all the more difficult to determine its value. This notwithstanding, below we have identified two primary areas where we believe the national ITS architecture has value, right now, for the transit industry: (1) a more conceptual understanding of transit as an integrated part of the transportation system; and (2) a technical framework for developing standards for the transit industry. These topics are discussed separately in the following sections.

2.2.1 Transit as Part of the Transportation System

The national architecture represents a significant portion of a more dramatic milestone reached by the federal government as part of the 1991 Intennodal Surface Transportation Efficiency Act, or ISTEA. For the first time in the nation's history, the authorization of federal support for the surface transportation system was promoted as supporting a *system,* and not just a collection of separate transportation modes and services. There is considerable debate about the impacts of this legislation, but one important element that was funded out of ISTEA was the national ITS architecture program.

What is most significant for the ITS program as a whole, and the national architecture effort more particularly, is the desire to consider an integrated surface transportation system. This "systems" thinking has been reflected in the documentation of the architecture program, and in the subsequent discussions at the federal level about the Intelligent Transportation Infrastructure (or ITI). This has important implications for the public transit industry, as will be described next. At the same time, this also can cause considerable confusion in discerning the "transit elements" of the national architecture. This subtle but important aspect of the national architecture is often neglected. In our view, this fact is part of the reason the architecture so quickly becomes complex and, to many, confusing.

From the very beginning, the architecture development program was asked to consider the full range of ITS services that may be available in the next 20 years in the United States. The advantage of integrating these services are many. Anyone developing and designing ITS-related products and services can:

- Avoid redundancy in data collection, processing, and analysis;
- Use similar hardware, software, and other technologies to perform a broader variety of tasks; and,
- Allow many agencies to share information with one another to manage the system as an integrated whole.

Thus, rather than considering one architecture for, say, public transit, and another for traffic management, a comprehensive architecture considering both aspects has been developed. In this way, services that cross traditional service or institutional boundaries are considered automatically. In the transit and traffic paradigm, a service giving buses priority at traffic signals is automatically considered, **both** as part of providing effective traffic control as well as providing improvements to bus on-time reliability.

As a result, in considering the (now) 30 user services, most, if not all, can be considered as having some long-term relevance to the public transit industry. Naturally, some are more directly connected to the current state of the transit industry. However, we do a grave disservice to the possible evolution of the transportation system of the future if we ignore some services that do not fall directly in transit's purview. This is perhaps where the analysis of PB Farradyne (1997a, 1997b) and Sandia (1994) fall short in not considering ITS services that extend beyond the six or seven that most directly relate to the public transit industry today.

The national architecture requires that the transit industry move a little out of the box to see that public transit is not just a single mode, but instead is an integrated part of the nation's transportation system. As such, it has an important role to play in the national ITS program, and in the architecture. Moreover, it should not be considered "independently" of other ITS services, as many of these services have something to bring to the operation and management of the public transit industry. In many cases, these services are inextricably linked with the evolution of public transit services.

2.2.2 Transit-related Standards

2.2.2.1 The Economic Value of Standards

It is generally assumed that standards for information systems and technologies in the transit industry is a good idea. Certainly, there has been considerable activity recently towards the development of technical standards for information systems and technologies in the transit industry, as was noted in Section 1.2. It is valuable, however, to look more closely at this assumption, to articulate both the potential value, as well as the potential costs, of such standards.

At a more abstract level, the value of standards in ITS, stemming from the activities of the national ITS architecture program, have been outlined by Hickman et al. (1996). The national architecture may be credited with reducing the initial system engineering and systems integration groundwork that is necessary for virtually any standards development process. This has two effects: it may reduce the time to develop standards; and, it may assist in scoping of appropriate message sets and interface definitions for the SDOs. These alone suggest that the architecture has some value in bringing standards to the industry faster than they would appear otherwise. However, the bigger question to discuss is whether the arrival of standards will have a significant and positive effect on the industry.

Benefits and Costs to Transit Agencies

To begin, there are significant benefits and possible disbenefits for transit agencies in having ITS standards. Three technical reasons for ITS standards are often characterized **as:**

- *Portability:* Components, hardware, software and other services may have "plug and play" capabilities.
- *Inter-operability:* Standard interfaces allow products and services to operate in conjunction with other vendor's products and services.
- *Data exchange:* Either "standard" data definitions between applications or standard interfaces allow unambiguous translation of data from one application to another.

All of these measures are important to the transit industry. Portability is likely to be a concern for transit agencies where (as is often the case) devices are not often moved from one vehicle to another. In addition, technical communication and coordination within transit agencies, and with vehicle fleets, may demand (i) the ability to mix-and-match software, hardware, and other technical components from a variety of vendors, and (ii) the ability to share data between applications.

Perhaps more importantly for the transit industry, public agencies may also receive economic benefits from standards. In the long run, standards may lead to:

- *An expanded choice ofproducts:* With product inter-operability, vendors can focus on supplying components that meet these interfaces, yielding a larger choice of products.

- *Economies of scale:* Cheaper costs to produce inter-operable APTS products and services will likely lead to lower costs to agencies buying these components.

At the same time, open interface standards mentioned above may also lead to undesirable impacts for APTS users. The danger here is that interface standards may lead to problems in terms of costs, technology compatibility, and long-term technology innovation.

- In the short term, early adopters of standards may, by the nature of an uncertain market for compatible products, pay considerable costs for "standardized" products and services. The financial "premium" for these early adopters can be substantial. In many cases, the initial price of a standardized product may be significantly higher than other (e.g. proprietary) existing systems. Also, if a market does not fully materialize, the early adopters may also face very high costs of operating and maintaining the system.

- More significantly, in the long term, the standards-setting process can lead to a choice of technology that is, in the longer term, inferior to other existing or emerging technologies. This may directly influence the long-term costs of purchasing, operating and maintaining the specific ITS products and services.

- Adoption of a particular standard does not necessarily imply that products will be compatible in the long run. First, if the standard is not universally adopted, early adopters may be "orphaned," with the result being high costs of operating, maintaining, and ultimately replacing the obsolete product. Second, given the rapid rate of innovation in information technologies, the life cycle of a particular product or service may outlast the value of the standard. That is, longer-tern cost savings and compatibility may not be realized if the standard is obsolete before the technology needs to be upgraded or replaced.

Even without much empirical evidence, it is believed that these potential costs are a significant deterrent to industry standards for APTS applications in public transit. Transit agencies may be hesitant to participate in standards development, for fear they would face higher product costs and/or be "orphaned" by standardized products.

Vendor Benefits and Costs

The adoption of industry consensus standards may lead to benefits for some APTS vendors and clear disadvantages for others. Benefits often cited for vendors include:

- *Igniting markets:* The existence of an industry-wide standard may be a key element in initiating a market. The existence of a standard allows significant economies of scale in production, bringing prices down sufficiently to have a market "take off."

- *Market expansion:* A diverse and expanded choice of products for a particular market may be developed, as vendors take advantage of variations in transit agency needs and tastes.

- *New technology insertion:* New or innovative technologies that are compatible with a standard interface may be introduced.

At the same time, open system standards may also have significant impacts on vendors and on the ITS industry as a whole. Where there are only a few (controlling) vendors for a particular product or service, as is often the case in the public transit industry, there are a number of major costs:

- Profit margins for vendors with proprietary or off-the-shelf integrated solutions are thus likely to decrease, discouraging their acceptance and use of the standard. At the same time, price competition has obvious benefits for end users.

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

Summary of Standards Impacts

Through open interface standards, the national ITS architecture has as its goal to provide a technical framework that will allow the development and long-term sustain-ability of a market for ITS. One of the main tools to achieve such market effects is to develop open interface standards for ITS products and services. Such standards may provide desired levels of compatibility, inter-operability, and cost savings that users need. On the other side, standards may help initiate and enlarge markets for ITS products and services, enhancing private vendor participation. Open interface standards may also spur considerable technology innovation in meeting user needs and tastes, and may also allow expansion to new technologies as they evolve. At the same time, the analysis above suggests significant risks and costs for both users and vendors associated with these efforts. While it is widely held that the benefits of such standards exceed the costs, this research study is intended to investigate this issue more directly to evaluate arguments for and against standards development.

2.2.2.2 The Development of Technical Standards

With this (often assumed) background to consider the potential value of standards, the transit industry in the United States has initiated both the TCIP and ISO TC 204 - WG **8** work to develop and gain industry acceptance of transit standards. In general, the current emphasis on transit industry-related standards fall into one of five different areas. The Institute of Transportation Engineers (ITE) Project Plan (1996) for developing the TCIP set of transit industry standards identifies the following as high-priority efforts under its charge:

1. Information transfer within the transit vehicle;
2. Interface of the transit vehicle with the transit management center and other transit fixed facilities;
3. Interface of the transit management center with other ITS-related centers (traffic management, emergency management, information providers, etc.); and,
4. Interface of the transit management center to fixed information devices (i.e., kiosks and other fixed display devices).

A fifth area for standards, somewhat within the realm above but more clearly identified across a broad range of ITS services, is mentioned by Okunieff (1996):

5. Data content, data transfer, and interfaces to heterogeneous location referencing systems for transit-related maps and spatial data bases.

Using the Open Systems Interconnection (OSI) seven-layer model for communications and interface protocols, the TCIP effort is engaged to develop standards primarily at the applications layer (layer 7). The applications layer establishes standards for what data will be communicated and what mechanisms are used to ensure those data are effectively transmitted across an interface.

It is perhaps in its most condensed form, the ***Standards Development Packages,*** that the logical and physical representations of the national architecture may be of most relevance to these efforts. The standards development packages are organized into the following 11 areas:

1. Dedicated Short Range Communications (DSRC)
2. Digital Map Data Exchange and Location Referencing Formats
3. Information Service Provider Wireless Interfaces
4. Inter-Center Data Exchange for Commercial Vehicle Operations
5. Personal, Transit, and HAZMAT Maydays
6. Traffic Management Subsystem to Other Centers (except EMS)
7. Traffic Management Subsystem to Roadside Devices and Emissions Monitoring
8. Signal Priority for Transit and Emergency Vehicles
9. Emergency Management Subsystem to Other Centers
10. Information Service Provider Subsystem to Other Centers (except EMS and TMS)
11. Transit Management Subsystem to Transit Vehicles and Transit Stops

Most of these packages are relevant to transit vehicles and/or transit management, except numbers 1 (primarily oriented to non-transit vehicles), 3 (primarily for personal, meaning private, devices), 4 (exclusively for commercial vehicles) and **7** (traffic management functions). It is relatively straightforward to see how the remaining packages relate to the five transit standards needs presented above:

(1) Within-vehicle communication is not addressed by the national architecture;
(2) Transit vehicle-to-management communications is covered in packages 5, **8** and 11;
(3) Transit management to other centers is covered in packages 6, **8**, **9** and 10;
(4) Transit management to fixed facilities is covered in package 11; and,
(5) Location referencing and map data base needs are addressed in package 2.

In essence, the standards development packages essentially re-organize information already in the logical and physical architecture. They include the following technical information:[2]

- *Message Transaction Sets:* in order to accomplish a given activity, a series of messages usually have to be exchanged between two or more subsystems. These messages, as a group, constitute a message transaction set. The sequencing of the messages is shown via an ISO-style message sequence chart. Typically the physical architecture flow or highest level logical architecture data flows represent individual messages.

- *Interface Decomposition:* This is the hierarchy of items that constitute an interface. It starts with the interface between two subsystems itself, which is then decomposed into physical architecture flows. Each of the physical architecture flows is then decomposed into its constituent logical architecture data flows, which in turn are decomposed until we reach primitive data elements. The physical architecture data flows are labeled with the type of communications technology appropriate for that flow. The logical architecture primitive elements are labeled with their size in bytes.

- *Communications Considerations* provides a discussion of the basic nature of the communications modalities that are suitable for supporting the interfaces in the particular standards requirements package. This section identifies some high level requirements, but the primary focus is to provide information that is viewed as useful to the initiation of the standardization process.

- *Constraints* lists the architecture flows and any constraints placed upon them.

- *Data Dictionary Elements:* entries taken directly from the logical architecture data dictionary. Each DDE provides a description of the data flow, and a definition of its composite data elements.

"...For purposes of analysis and discussion, the National ITS Architecture has been portrayed as having three layers: *the transportation, the communications, and the institutional layer.* The first two are of concern here. The transportation layer contains all the functionality of the National ITS Architecture. As a consequence, any discussion of interfaces, messages, data dictionary entries, etc. is drawn from the information in the transportation layer. The communications layer describes the technology required to support the information exchange needs of the transportation layer. These National ITS Architecture layers can be roughly mapped to the ISO OSI reference model; the transportation layer is typically at or above the application layer [7] and the

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[2]This information is taken directly from the leading material in the Standards Development Packages from the National ITS Architecture Program Documentation.

communications layer is most often concerned with the lowest four layers **[1-41** of the ISO OSI reference model."

Hence, the standards development packages are primarily intended to give standards development organizations the raw material they need to begin developing both the application and communication-level protocols necessary for APTS.

2.3 Basic Transit-related Elements

For the sake of completeness, this section gives a very brief overview of the transit-related elements of the national architecture. For the purposes of this study, the following are the major elements of the physical architecture that will be considered:

- Transit subsystems (physical entities) in the architecture
- Architecture interfaces and flows between these subsystems

These are identified in separate sections below, and will be used more extensively in subsequent white papers.

2.3.1 Transit-related subsystems

For the purposes of this research, it may be useful to divide the physical entities in the national ITS architecture into two groups: those most essentially in the transit realm, and those that form services that require cooperation and functions outside typical transit operations and management. In the first category, we would place three essential transit subsystems, described below with their corresponding description (at a ***complete*** level of ITS functionality) from the ***Physical Architecture*** document.[3]

1. The ***Transit Management*** subsystem (abbreviated **TRMS).** The Transit Management

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[3]From the National ITS Architecture documentation, 1996.

subsystem provides the capability for determining accurate ridership levels and implementing corresponding fare structures. The fare system shall support travelers using a fare medium applicable for all surface transportation services. The subsystem also provides for optimized vehicle and driver assignments, and vehicle routing for fixed and flexibly routed transit services. Interface with the Traffic control shall be integrated with traffic signal prioritization for transit schedule adjustments and the transit vehicle maintenance management shall be automated with schedule tracking. The Transit Management Subsystem also provides the capability for automated planning and scheduling of public transit operations. The subsystem shall also provide the capability to furnish travelers with real-time travel information, continuously updated schedules, schedule adherence information, transfer options, and transit routes and fares. In addition, the capability for the monitoring of key transit locations with both video and audio systems shall be provided with automatic alerting of operators and police of potential incidents including support of traveler activated alarms.

2. The ***Transit Vehicle*** subsystem (abbreviated TRVS). This subsystem resides in a transit vehicle and provides the sensory, processing, storage, and communications functions necessary to support safe and efficient movement of passengers. The Transit Vehicle Subsystem collects accurate ridership levels and supports electronic fare collection. An optional traffic signal prioritization function communicates with the roadside subsystem to improve on-schedule performance. Automated vehicle location functions enhance the information available to the Transit Management Subsystem enabling more efficient operations. On-board sensors support transit vehicle maintenance. The Transit Vehicle Subsystem also furnishes travelers with real-time travel information, continuously updated schedules, transfer options, routes, and fares.

3. The ***Remote Traveler Support*** subsystem (abbreviated **RTS**).This subsystem provides access to traveler information at transit stations, transit stops, other fixed sites along travel routes, and at major trip generation locations such as special event centers, hotels, office complexes, amusement parks, and theatres. Traveler information access points include kiosks and informational displays supporting varied levels of interaction and information access. At transit stops, simple displays providing schedule information and imminent arrival signals can be provided. This basic information may be extended to include multi-modal information including traffic conditions and transit schedules along with yellow pages information to support mode and route selection at major trip generation sites. Personalized route planning and route guidance information can also be provided based on criteria supplied by the traveler. In addition to traveler information provision, this subsystem also supports public safety monitoring using CCTV cameras or other surveillance equipment and emergency notification within these public areas. Fare card maintenance, and other features which enhance traveler convenience may also be provided at the discretion of the deploying agency.

As noted in these descriptions, these three subsystems provide the fundamental services typically associated with public transit.

A second set of subsystems may also be identified within the architecture that share data and information with these three primary subsystems. The following list describes the subsystems (i.e., other entities *within* the architecture) from the architecture that are specified to share data and information with the TRMS, TRVS, and RTS (listed alphabetically):[4]

- ***Emergency Management*** subsystem (EM): This entity operates in various emergency centers supporting public safety including police and fire stations, search and rescue special detachments, and HAZMAT response teams.

- ***Information Service Provider*** subsystem (ISP): This subsystem provides the capabilities to collect, process, store, and disseminate traveler information to subscribers and the public at large.

- ***Personal Information Access*** subsystem (PIAS): This subsystem provides the capability for travelers to receive formatted traffic advisories from their homes, place of work, major trip generation sites, personal portable devices, and over multiple types of electronic media.

- ***Parking Management*** subsystem (PMS): This subsystem provides the capability to provide parking availability and parking fee information, allow for parking payment without the use of cash with a multiple use medium, and support the detection, classification, and control of vehicles seeking parking.

- ***Planning*** subsystem **(PS):** This entity provides planning information and support for facilitating deployment and operation of ITS services.

- ***Roadway*** subsystem (RS): This subsystem includes the equipment distributed on and along the roadway (and wayside) which monitors and controls traffic.

- ***Traffic Management*** subsystem (TMS): This subsystem operates within a traffic management center or other fixed location. This subsystem communicates with the roadway subsystem to monitor and manage traffic flow.

- ***Vehicle*** subsystem (VS): This subsystem resides in an automobile and provides the sensory, processing, storage, and communications functions necessary to support efficient, safe, and convenient travel by personal automobile.

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[4]Again, these are taken from the **Physical Architecture** documentation.

In addition to the subsystems identified above, transit agencies also interface with many entities that are listed in the architecture as *terminators.* Terminators in this sense characterize people, components or organizations that are not directly performing the functions required for an ITS system, but provide an important interface to the ITS system. Terminators that interface with the TRMS, TRVS and RTS include:'

- ***Intermodal Transportation Service Provider*** terminator (X02): This terminator provides the interface through which various other transportation service providers can exchange data with ITS. They are the operators of non-roadway transportation systems (e.g. airlines, ferry services, passenger rail).

- ***Financial Institution*** terminator (X21): This terminator represents the organization that handles all electronic fund transfer requests to enable the transfer of funds from the user of the service to the provider of the service. The functions and activities of financial clearinghouses are within this entity.

- ***Map Update Provider*** terminator (X23): This terminator represents a third-party developer and provider of digitized map databases used to support ITS services.

- ***Other Transit Management*** terminator (X33): Representing another transit management subsystem (TRMS), this terminator is intended to provide a source and destination for ITS data flows between peer (e.g inter-regional) transit management functions. It enables traffic management activities to be coordinated across geographic boundaries or different jurisdictional areas.

- ***Secure Area Environment*** terminator (X42): This terminator comprises public access areas that transit users frequent during trips (such as bus stops, park and ride facilities, internal areas of transit vehicles, at kiosks, and other transit transfer locations). These environments are monitored as part of the ITS architecture functions to promote transit safety.

- ***Transit Manager*** terminator (X47): This terminator represents the human entity that is responsible for planning the operation of transit fleets, including monitoring and controlling the transit route schedules and the transit maintenance schedules. This comprises planning routes and schedules for either daily use or for special occasions as distinct from making day

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'Also taken from the **Physical Architecture** document.

to day variations to schedules and routes.

- ***Transit System Operators*** terminator (X49): This terminator represents the human entities that are responsible for all aspects of the transit subsystem operation including planning and management. They actively monitor, control, and modify the transit fleet routes and schedules on a day to day basis. These personnel may also be responsible for demand responsive transit operation and for managing emergency situations within the transit network.

- ***Transit User*** terminator (X50): This terminator represents the human entities using public transit vehicles. They may be embarking or debarking the vehicles and are thus sensed to determine passenger loading and fares, or on the vehicles and thus able to request and receive information.

- ***Transit Vehicle*** terminator (X51): This terminator represents a specialized form of the Basic Vehicle used by transit service providers. It supports equipment to collect fares, monitor activities, request priority at signals, and provide information to travelers. The monitoring of the transit vehicle mechanical condition and mileage provides the major inputs for transit vehicle maintenance scheduling.

- ***Transit Driver*** terminator (X52): This terminator represents the human entities driving (or operating) public transit vehicles.

- ***Transit Maintenance Personnel*** terminator (X53): The terminator represents the human entity that is responsible for monitoring, controlling, and planning the schedules for the maintenance of transit fleets.

- ***Traveler*** terminator (X56): This terminator represents any individual (human) who uses transportation services. At the time that data is passed to or from the terminator the individual is neither a driver, pedestrian, or transit user. This means that the data provided is that for pre-trip planning and includes their requests for assistance in an emergency. Subsequent to receipt of pre-trip information, a Traveler may become a vehicle driver, passenger, transit user, or pedestrian.

- ***Payment Instrument*** terminator (X61): This terminator represents the entity that enables the actual transfer of funds from the user of a service to the provider of the service. This terminator can be as abstract as an account number, or as real as the electronic tag.

- ***Enforcement Agency*** terminator (X62): This terminator represents an external entity which receives reports of violations detected by various ITS facilities, e.g. toll and fare violations, etc.

2.3.2 Transit interfaces and architecture flows

Given this list of entities that is supposed to be communicating with the transit management, transit vehicle, and remote traveler location subsystems, one might then ask what kind of information might be (or should be) passed between systems to ensure a well-integrated operation of the ITS system. The architecture defines the set of information passing between entities in two ways: (1) simply by describing an ***interface*** where information should be shared, and (2) by describing particular sets of information, or ***architectureflows,*** that are shared between two entities in a fully functional ITS system.

At the highest level, the list of entities mentioned above can be used to construct logical connections between systems that should share information. Across the broad range of ITS services, a set of transit-related interfaces is depicted in Figure 2-2.[6] In this diagram, the shaded boxes represent subsystems, the boxes with rounded comers represent terminators, and a line connecting entities indicates an interface. Each interface shown in the diagram means that, in a fully built-out ITS system, there will be data or other information shared between these two entities, and hence might require a formal definition of an interface between these two entities.

Note that the connections in this diagram come from the rigorous systems engineering techniques associated with the development of the physical architecture. Once functions are

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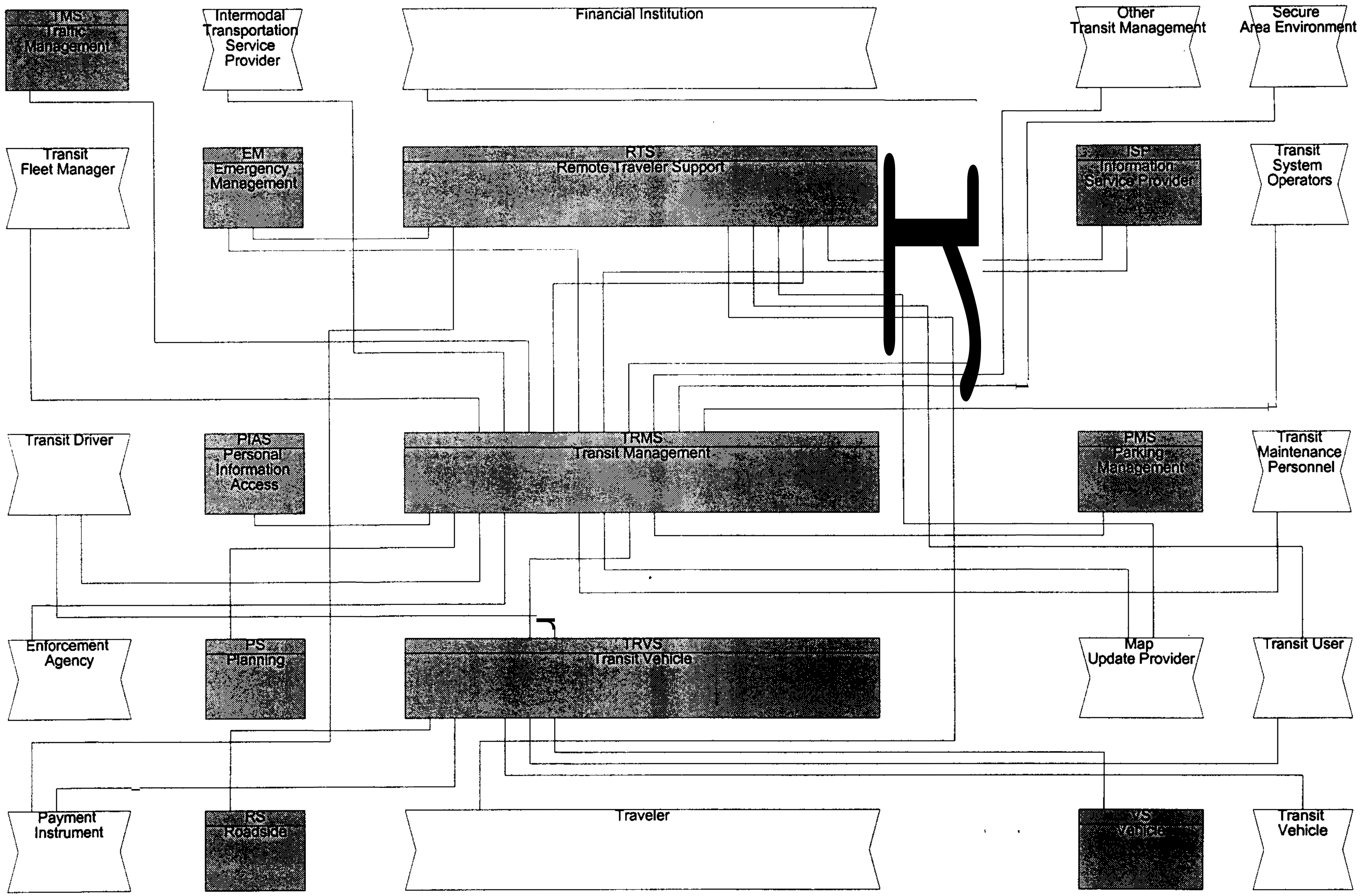
[6]The authors are deeply indebted to Jim Larson of Rockwell International who graciously allowed us to use his **"autoplot"** program to generate the architecture schematics in this report.

Figure 2-2: Transit-Related Interfaces



partitioned among physical entities, data flows between those functions define a necessary sharing of data, traveling between the physical entities. Whenever such a data flow exists, it necessarily requires an interface between these objects. Thus, Figure 2-2 presents the highest level depiction of transit-related data or information flows between physical entities in the architecture. These are precisely the interfaces that are specified in the ***Standards Requirements Packages*** mentioned previously.

Moreover, these interfaces can be further decomposed into specific *architectureflows,* and more directly into data flows and message sets. **As** an example, one might be tempted to look more specifically at the kinds of messages that might be sent to and from a transit management center (or subsystem), or what messages might be sent to and from a transit vehicle. This information is contained in several places in the architecture: in the ***Physical Architecture,*** in the ***Theory of Operations*** document, and in the ***Standards Requirements Packages.*** The purpose is to indicate what types of information might be sent in specific, bundled "messages" to and from each of these subsystems in the architecture.

As examples, Figures 2-3, 2-4 and 2-5 indicate the *architectureflows* to and from Transit Management subsystem (TRMS), the Transit Vehicle subsystem (TRVS), and the Remote Traveler Support (RTS) subsystem, respectively. These diagrams indicate the types of messages that might be relayed in and out of these entities in an operating ITS system. In bundling the various data flows into more specific messages, and then into architecture flows, data are aggregated based on criteria such as: likely frequency of use (e.g. regular polling versus exceptions), the use of various data in common functions (e.g. transit dispatch), and the needs of various different personnel and areas within the agency for each kind of data.

Figure 2-3: Architecture Flows to and from the TRMS

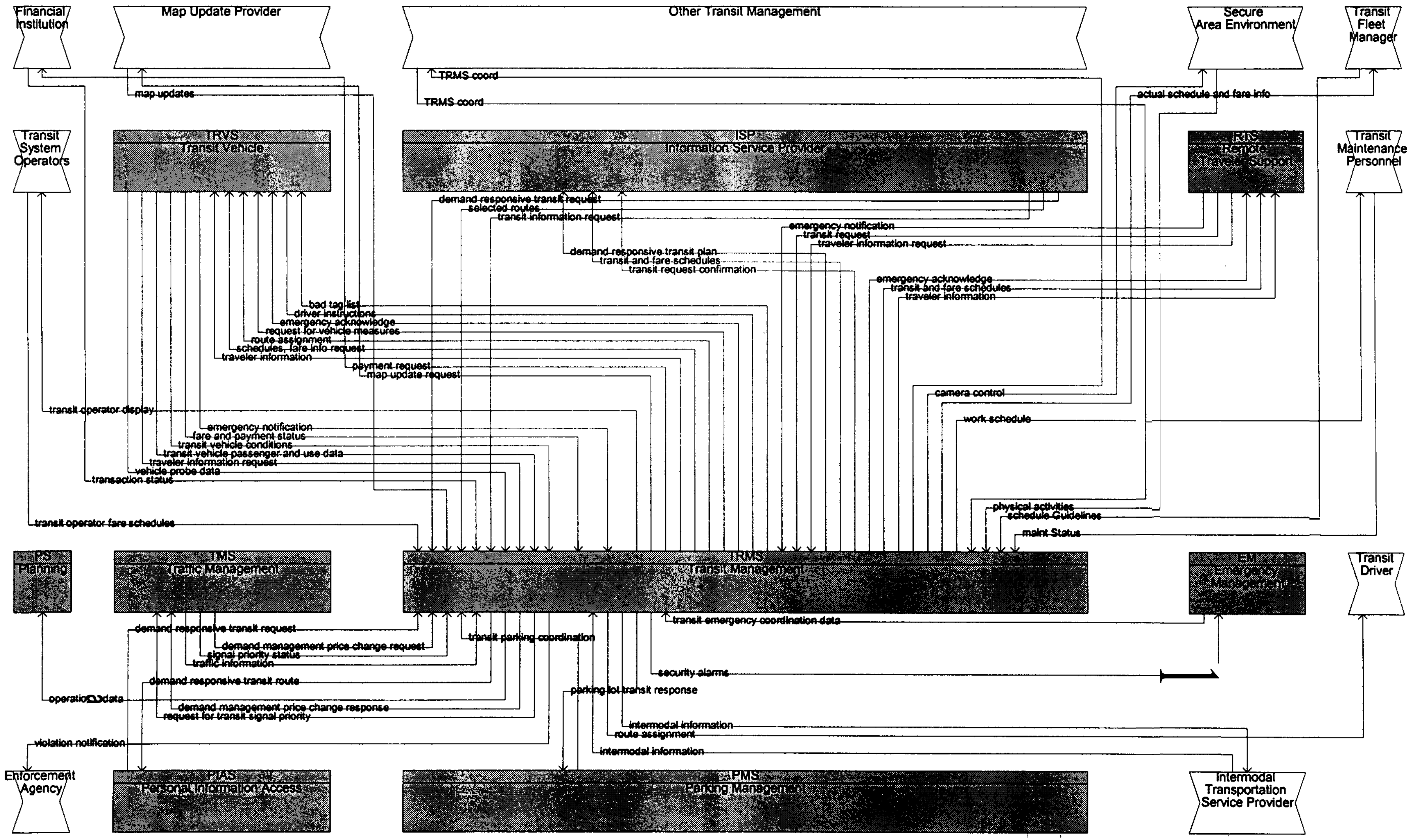


Figure 2-4: Architecture Flows to and from the TRVS

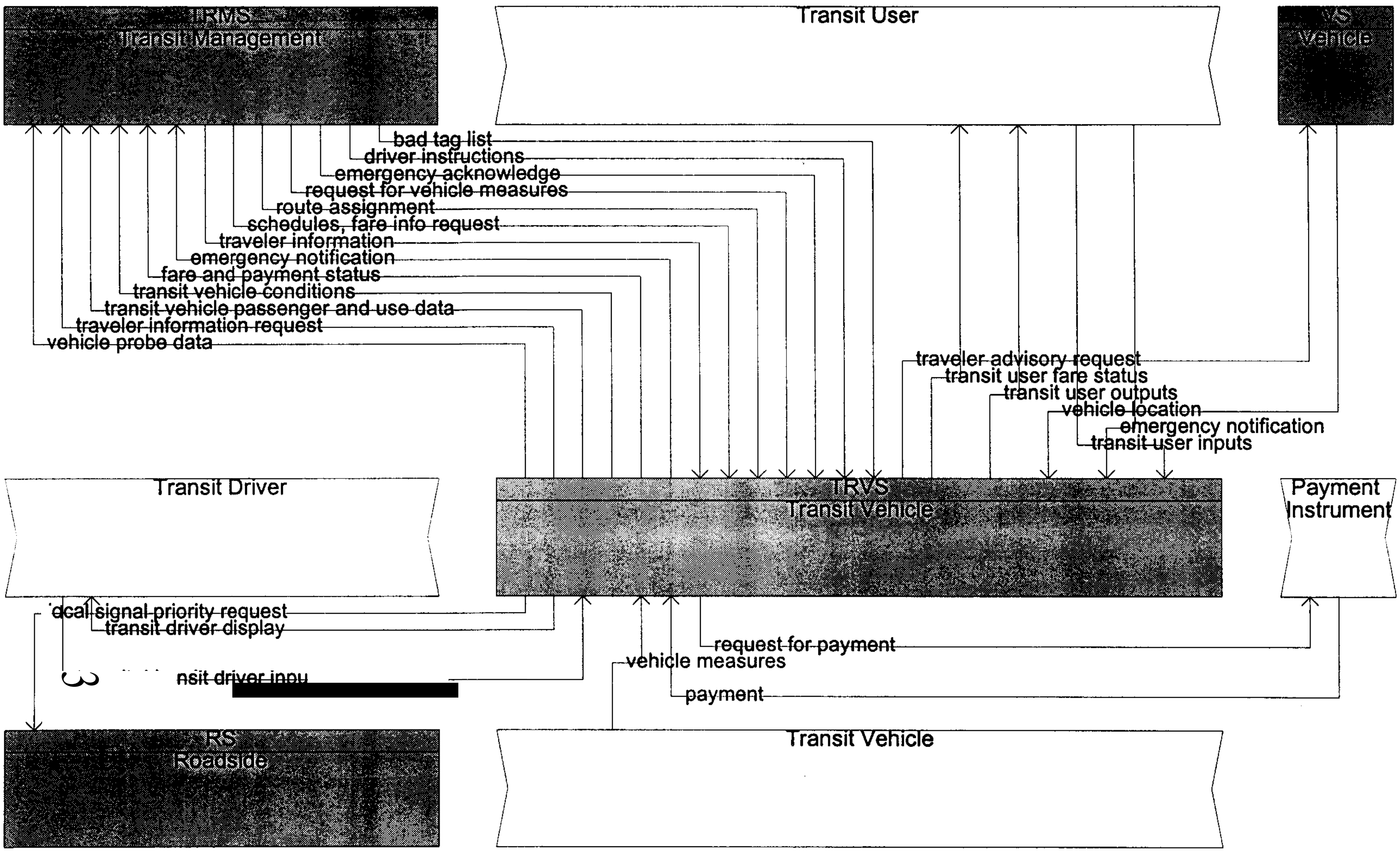
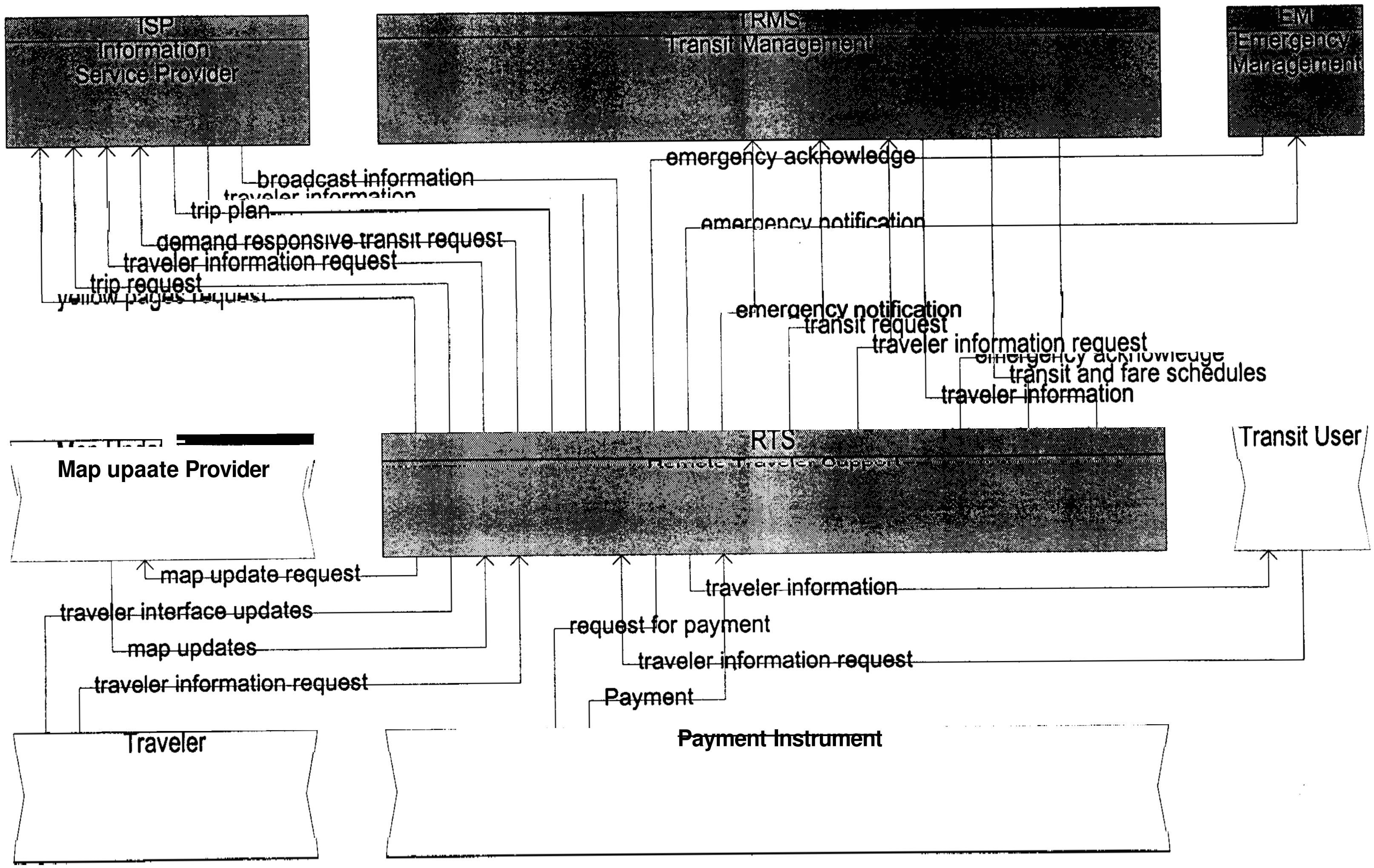


Figure 2-5: Architecture Flows to and from the RTS



As an example, Figure 2-3 indicates separate messages from the Transit Management subsystem to differentiate demand-responsive service requests, which are likely to be frequent but spontaneous, with fixed-route schedules and fares, which are likely to be needed infrequently and can often be planned or anticipated. Architecture flows from the Transit Vehicle, shown in Figure **2-4,** demonstrate different needs and priorities of messages: emergency notification (such as a "silent alarm") is one type of message to be needed only on an exception basis but with high priority. Other messages, such as vehicle probe data (vehicle location, etc.) and vehicle conditions may be reported more regularly. Finally, in Figure 2-5, representative architecture flows distinguish between messages for emergency notification versus more frequent and regular updates of traveler information and route, schedule and fare requests.

This information is simply intended to hint at the wealth of information contained in the national architecture documentation. Several challenges now await those in the transit industry trying to make use of this national effort. The first is to develop a more useful and constructive set of architecture documentation for the transit industry; this is now underway from PB Farradyne (1997a and 1997b). A second challenge is to use this information effectively to improve standards development efforts, such as the Transit Communications Interface Profiles (TCIP) efforts now in earnest. A third element is to discern the implications of the architecture on current practice in the transit industry. This is the challenge of this study, and subsequent chapters address these issues more concretely.

3 Synthesis and Development of Related Material

For various reasons, the national ITS architecture described in Chapter **2** is necessarily insufficient for transit purposes. The shortcomings of the architecture are traced in part to several factors, including:

- The transit industry had only limited input and exposure to the transit-related "User Services" in the original "User Service Requirements'' that were given to the architecture development teams. Because of this, one might question whether the user service requirements are accurate and comprehensive of the many functions and information flows that occur in any transit agency.
- The architecture development effort, for various technical and institutional reasons, did not find much material that was directly transferable from the preliminary study of Sandia National Labs (1994).
- The definition of subsystems and information flows within the architecture was not at a sufficient level of detail to describe the many internal interfaces commonly found in the transit industry. It is often the data flows among various organizational units within a transit agency, or those among devices on board a transit vehicle, that need the most urgent attention.
- There was a considerable lack of exposure and feedback from the public transit industry as part of the national ITS architecture development process. Various review meetings and regional workshops were either not open to the public, or were generally not attended by the public transit industry.

Currently, out of these deficiencies has come the effort by PB Farradyne (1997a and 1997b) to "re-package" the national architecture for the transit industry. More recently, the TCIP working group (1996) has been commissioned to look more specifically at the data flows and interfaces that are specific to the needs of ITS technologies in the transit industry. The TCIP effort, while focusing on object and message sets for transit, has lost the context of a "physical architecture" and the higher-level information flows that characterized the national architecture. What is still needed, then, is a common architecture that reflects the specific needs of the transit industry, but which maintains a somewhat obvious link to the national ITS architecture. The means and end product of such a development effort are described in this section.

3.1 Additional Lessons Learned from Sandia's Study

The work of Sandia National Labs (1994), was intended to provide an "architecture" as a synthesis of current and near-term applications of APTS in the transit industry. While it was not developed rigorously using traditional top-down systems engineering principles (generation of functional requirements, functional decomposition, etc.), the Sandia effort represented a physical representation of many of the communication links that commonly occur in transit agencies. In this sense, the Sandia effort provided a "real-world'' sense of a technical system architecture for the transit industry.

There were several features of the Sandia architecture that warrant further attention. Specifically, the Sandia architecture provides some important insights into the specification of important interfaces and functional roles within a transit agency. These are summarized below.

The Sandia architecture provided for the following major subsystems:

Vehicles
B 1. Buses
B2. Demand-responsive vehicles
B3. High-occupancy vehicles (HOVs)
B4. Maintenance vehicles
B5. Rideshare vehicles
B6. Supervisory vehicles
C1. Commuter rail vehicles
C2. Heavy rail vehicles
C3. Light rail vehicles

Management
D1. Commuter rail operations center
D2. Incident management center
D3. Information clearinghouse
D4. Maintenance facilities
D5. Other city and state departments and services
D6. Rail operations center
D7. Traffic management center
D8. Transit administration offices
D9. Transit operations center

Other Facilities
E1. Individuals
E2. **Kiosk**
E3. Roadside nodes
E4. Taxi dispatch center

It is curious to note that many of the subsystems in the Sandia study match those that were defined as part of the national ITS architecture. Of importance to this study is that the Sandia work further subdivided the transit vehicle into many separate vehicles, based on the anticipated communications requirements of each vehicle type. Also of importance is the separation of modal operations centers and the transit maintenance (or garage) facilities, which suggest important interfaces between organizational units that may present technical and/or institutional challenges in bridging information needs of these groups. Because this detailed level of system specification exceeded that of the national architecture, it was decided to retain some of this structure in the development of a new common architecture.

The Sandia study also gave a physical interpretation of information flows between their subsystems. Specifically, they identified the existence of communications links between the subsystems identified above, and described whether each link would be typically managed as a (i) wireless or wireline link; and, (ii) a voice or data communications requirement. As some of these decisions are clearly driven by the current economics and available technology, much of Sandia's work to define interfaces is considered to be too technology-driven and technology-dependent. For this reason, the interfaces defined by Sandia have only limited value in defining data flows between various subsystems used in public transit.

3.2 Toward a More Detailed Architecture

Using the raw material from the Sandia study and the work of the national architecture development teams, we took the best parts of each and compiled a common list of transit subsystems and information flows. The following sections outline both the components and communications links that seem to be a reasonably comprehensive representation of an architecture for the transit industry.

3.2.1 Transit subsystems

Table 3-1 gives a composite set of subsystems based on the national ITS architecture and the work of Sandia. Within the table, the proposed subsystem (and acronym) are given, and the corresponding entities fi-om Sandia and the national systems architecture **(NSA)** are also shown.

In general, the specification of subsystems generally follows the proposed by Sandia, with several exceptions. For the most part, each of the vehicle types specified in the Sandia architecture were maintained; the only exceptions made here were to roll together the Heavy and Commuter Rail Vehicles (HRV) and the Maintenance and Supervisory Vehicles (MSV). These were done based on likely similarities in communications requirements and information flows to

Table 3-1 : Proposed Transit Subsystems

Acronym	Subsystem Name	Sandia Node	NSA Entity
ADM	Transit Planning and Administration	D8	TRMS
DRV	Demand-Responsive Vehicle	B2	TRVS
EM	Emergency Management	D2	EM
FCH	Financial Clearinghouse	---	X21
FRV	Fixed- or Flexible-Route Bus	B1	TRVS
HOP	Heavy/Commuter Rail Operations	D1	TRMS
HOV	Private HOV Vehicle	B3	TRVS
HRV	Heavy / Commuter Rail Vehicle	C1/C2	TRVS
ISP	Multimodal Information Service Provider	D3	ISP
LOC	Local Public Services	D5	X62
LOP	Light Rail Operations	D6	TRMS
LRV	Light Rail Vehicle	C3	TRVS
MAP	Map and GIS Update Provider	D5	X23
MNT	Transit Maintenance and Garage	D4	X53
MSV	Maintenance and Supervisory Vehicle	B4/B6	TRVS
PAY	Payment Instrument	---	X61
PIA	Personal Information Access	E1	PIAS
RS	Roadway / Wayside	E3	RS
RSV	Ride-Share Vehicle	B5	TRVS
RTS	Remote Traveler Support	E2	RTS
TDC	Taxi Dispatch	E4	TRMS
TM	Traffic Management	D7	TMS
TOP	Transit Operations	D9	TRMS

and from these types of vehicles. Also maintained from the Sandia Architecture is the breakdown of transit management into several distinct entities, including the operations center (for each mode), a separate maintenance (or garage) entity, and a separate subsystem for transit administration and planning. Because of the myriad types of software and hardware that are associated with operations, maintenance and planning, the interfaces between these entities seemed important considerations for the proposed architecture.

Also included in the final architecture are several elements that did not appear as distinct entities in the Sandia architecture but which occurred in the national ITS architecture. These include, primarily, entities related to payment services: a payment instrument (e.g. a smart card), and a financial clearinghouse to manage financial (transit fare) transactions.

For completeness, we offer the following definitions of each of the proposed entities:

- Transit Planning and Administration (ADM) - is responsible for all non-operational aspects of a public transportation system. From the ITS standpoint, service analysis, financial record keeping, and federal reporting are the major functions.

- Demand-Responsive Vehicles (DRV) - follows a flexible route responding to the needs of the passengers. The vehicles are operated by a transit authority or by a privately owned corporation under contract to a transit authority.

- Emergency Management (EM) - coordinates and responds to unusual or emergency conditions in an area. It has access to data from all mode operations centers, and from Traffic Management Centers to facilitate response to major emergencies and coordinating traffic control.

- Financial Clearing House (FCH) - handles funds transfers to reconcile and reimburse the appropriate agencies for fares and tolls collected from users of the system.

- Fixed- or Flexible-Route Bus (FRV) - is a motorized highway operated vehicle. It can be owned and operated either publicly or privately under a contract. It normally follows a fixed route; however deviations from the route and return to the fixed route are anticipated.

- Heavy/Commuter Rail Operations Center (HOP) - is responsible for all operations involving commuter and heavy rail services.

- Private HOV Vehicles (HOV) - are usually cars or vans owned by a private owner, or provided by an employer to bring employees to the workplace. Although the route is not usually fixed, the origin and destination points are usually constant.

- Heavy / Commuter Rail Vehicles (HRV) - Heavy rail is a rail system specifically designed for mass transit with exclusive track ownership. Commuter rail is a regional passenger rail service tailored for commuter needs. The service is often provided under contract to transit authorities and generally shares track with other rail operations. Both systems can be either operated by a public agency or contracted out to a private operator.

- Multimodal Information Service Provider (ISP) - provides real time schedule information for intermodal connections, including air, rail, and other transportation modes. The provider has the capability to provide a specific itinerary to travelers given the time of travel and origin and destination points.

- Local Department and Services (LOC) - consists of all non-transit organizations involved in local services (fire, ambulance, police, etc.).

- Light Rail Operations Center (LOP) - handles all aspects of the operational side of passenger light-rail services in an urban area, including traffic light preemption.

- Light Rail Vehicles (LRV) - are specifically designed for mass transit applications. They may include operations on surface streets and may require coordination with traffic lights. The system can be operated by a public agency or contracted out to a private operator.

- Map and GIS Update Provider (MAP) - is responsible for establishing and maintaining GIS databases and digital maps used by the transit agency for planning, route guidance, operator display, and traveler information.

- Transit Maintenance and Garage (MNT) - represents the maintenance function of transit. This node is responsible for monitoring, controlling, and planning regularly scheduled maintenance. It must also have the capability for needs-based maintenance.

- Maintenance and Supervisory Vehicles (MSV) - are responsible for maintaining and servicing vehicles and equipment of the transit authority, while supervisory vehicles provide supervision of operations. They can be either operated by the transit authority or contract out to private operators. The routes are flexible and depend on the needs of the equipment and transit vehicles.

- Payment Instrument (PAY) - is the mechanism used to receive fares on the transit vehicle. It includes smart cards, smart card readers, and fare boxes.

- Personal Information Access (PIA) - Provides communication between individuals and the public transportation system. Communication can be either one-way or two-way.

- Roadway / Wayside (RS) - refers to communication facilities on the roadside or wayside that are used by transit vehicles.

- Ride-Share Vehicles (RSV) - is a private (or public) vehicle where passengers are matched with private drivers in real time. Drivers inform the system of their trip plan, and the system requests the drivers to pick up potential passengers with small deviations to their routes. The drivers are compensated by access to the HOV lanes and/or fares.

- Remote Traveler Support (RTS) - provides transit information to kiosks located in public or private facilities. Functions include planning intermodal trips, making reservations, ticket purchasing, weather reports and parking availability.

- Taxi Dispatch Center (TDC) - provides dispatching capabilities for ride-share vehicles and taxi operations to fill gaps in normal transit service. Taxi services may also synergistically support transit operations. For example, taxis could perform neighborhood pickup, and bringing passengers to a fixed bus route.

- Traffic Management (TM) - coordinates and manages urban highway traffic, especially congestion problems. It handles non-emergency types of traffic problems, including HOV management and congestion pricing, especially for deviations from normal scheduled operations. Emergencies are reported to and monitored by the Emergency Management.

- Transit Operations Center (TOP) - is responsible for all aspects of daily operations in a public transportation system. It handles primarily buses and paratransit services.

3.2.2 Transit architecture flows

Using the *Theory of Operations* document from the national ITS architecture (1996), and the Sandia transit communications diagrams, a common set of architecture flows was created. In the national architecture, these architecture flows include the flows to and from the transit management subsystem, to and from the transit vehicle subsystem, and to and from the remote traveler support subsystem. In the case of flows to and from the transit management subsystem, these needed to be connected to the entities mentioned above (Table 3-1). To do this, engineering judgment was used to assign the flows to the transit operations (TOP, LOP and HOP), transit planning and administration (ADM), and/or transit maintenance and garage (MNT), based on whether the flow was related to operations, planning and administration, or maintenance, respectively. For the flows to and from the transit vehicle, best engineering judgement was used in carrying over these flows to all the various types of vehicles (DRV, FRV, HOV, HRV, LRV, MSV and RSV).

Furthermore, the interfaces specified in the Sandia architecture were also identified. In most cases, these flows could be directly connected to the entities proposed in Section 3.2.1. However, because the Sandia architecture did not directly specify the content of these communication flows, the original Sandia documentation and best engineering judgment was used to estimate the content of each of the Sandia architecture links.

With the two sets of information flows, redundancies between the NSA and Sandia were eliminated. This yielded a total of 264 architecture flows, which can be grouped into the 53 unique architecture flows shown in Table 3-2. The full set of architecture flows is shown in Appendix A. These create a set of "messages," or meaningful collections of data and information, that must be transmitted for an APTS application.

3.2.3 Using the Architecture

At any one transit agency, for any set of APTS technology applications, only a handful of the entities and data flows could be identified. For example, Chapter ***5*** identifies case study sites for which these information flows are applied; each of these consists of approximately 20-30 flows, together with a handful of entities (subsystems).

To use this architecture, one might specify a particular kind of APTS application. With this application, one might identify, using typical organizational units and existing hardware and software components, the set of entities from Table 3-1 that match the desired application. Based on these entities, all the architecture (information) flows that might go into or out of each entity can be identified, using the entity names and finding all the associated flows (in and out) from Appendix **A.** The user may also wish to eliminate certain flows that do not entirely match

Table 3-2: Proposed Transit Architecture Flows

Architecture Flow	Flow Description
Bad Tag List	List of invalid charge or value card numbers
Demand-Responsive Trip Confirmation	Acknowledge request for trip and provide scheduled service information
Demand-Responsive Trip Request	Request for demand-responsive trip
Driver Instructions	Instructions for paratransit driver
Electronic Tolls	Current toll schedules for different types of vehicles
Emergency Acknowledge	Acknowledge request for emergency assistance and provide additional actions and
Emergency Notification	Mayday notification by a traveler. Could be on foot, or in any vehicle.
Emergency Notification and Vehicle Conditions	Mayday notification from a vehicle, including current vehicle status information
Emergency Response Coordination	Coordination information between Emergency Management (EM) and transit
Fare and Payment Status	Current status of cash box on transit vehicle
Federal Reporting Data	Information required by federal reporting requirements
Flexible-Route Request Confirmation	Acknowledge request for trip and provide scheduled service information
Flexible-Route Transit Request	Request for a flexible-route transit pick-up or drop-off
GIS/Map Update	Either static or real-time map updates
Incident Reporting	Incident imagery and other data from incident site
On-board Information	Current status on board the transit vehicle
On-board Security Control	Control of on-board devices to capture security information
Operational Cost Data	Information requested by authorities to monitor transit operating costs
Parking Availability	Parking lot occupancy and availability
Parking Lot Data Request	Request for lot occupancy, fares, availability
Payment	Payment of some kind by user
Payment Requests	Request for payment from financial institution
Personal Security Alarm	Security alarms located in transit stops or on board transit vehicles
Physical Activities	Video or other information for monitoring secure areas and public stops or kiosks
Real Time Multimodal Information	Information on current traffic conditions, routing, etc. for a traveler
Repair Requests	Notification and request for repair of transit vehicle
Request for Toll Schedules	Request made to obtain toll schedule information
Request for Traffic Information	Request issued to agency which collects traffic data for traffic conditions
Request for Transit Signal Priority	Request for signal priority either through roadside or directly to TM
Route Guidance	Specific instructions to travelers in executing a multimodal travel / trip itinerary
Route Planning	Data necessary for the development of transit schedules, fares, and routing
Routing Information	Multimodal travel / trip itinerary
Schedule and Fare Information	Transit schedule and fare information as well as current demand response route
Schedule Generation	Specific fixed-, flexible-, and demand-responsive schedules from transit management
Service Coordination	Coordination information between transit organizations (schedules, on-time status, etc.)
Taxi Coordination	Coordination information between transit organizations and taxi dispatchers
Ticket Purchase	Confirmation and credit of fare payment to payment media
Ticket Purchase Request	Request to purchase appropriate fare for payment media
Toll Schedules	Current toll schedules for different types of vehicles
Traffic Information	Congestion, pricing, and incident information
Transaction Status	Response to transaction request. Normally dealing with request for payment
Transit Information Request	Request for transit schedule information
Transit Passenger and Use Data	Aggregated data of passenger loads and fare transactions from the transit vehicle
Transit Vehicle Passenger and Use Data	Data collected on board the transit vehicle
Traveler Information	Traveler routing, yellow pages etc...
Traveler Information Request	Request for any type of traveler information
Trip Confirmation	Acknowledgment of acceptance of route
Trip Reservation	Request for reservation for a demand-responsive transit trip
Trip Reservation Confirmation	Acknowledge request for reservation and provide scheduled service information
Vehicle Location and Conditions	Current vehicle location data and the conditions of transit vehicle for maintenance
Vehicle Probe Data	Single vehicle probe data indicating link time and location.
Violation Notification	Notification to enforcement agency of violation or regulations
Yellow Pages	Information on local businesses, services, etc.

their desired application. However, the use of architecture flows can help to identify the important communication interfaces that will be necessary in the system design, and the important messages that may need to be communicated over each interface.

4 An Alternative View: Current APTS Products and Services

The architecture developed above takes largely a top-down view. That is, by traditional systems engineering approaches, a set of functional subsystems and data interfaces can be identified. This may, however, contrast significantly with current practice, and may ultimately not prove useful in the larger context of the development of transit interface standards (e.g., the TCIP family of standards). To explore this question, the research examined currently available APTS products and services, and tried to match these with the open system architecture described in Chapter **3.** This chapter highlights major vendor issues and a survey that was conducted to solicit vendor approaches to interface specification.

4.1 Anticipated APTS Vendor and Product Issues

The effort being conducted under TCIP is an effort to bring transit agencies, long seen as the beneficiaries of higher standardization in the transit industry, together with the industry's product and service vendors. While the qualitative arguments on the benefits to public transit agencies appear compelling, the case for vendors is not as clear. This is especially true in transit where there are several product markets that are dominated by a small collection of vendors who have a strong interest in retaining their market share.

At a more conceptual level, the adoption of industry consensus standards may lead to benefits for some APTS vendors and clear disadvantages for others. Benefits often cited for vendors include:

- ***Igniting markets:*** The existence of an industry-wide standard may be a key element in initiating a market. The existence of a standard allows significant economies of scale in production, bringing prices down sufficiently to have a market "take off."

- *Market expansion:* A diverse and expanded choice of products for a particular market may be developed, as vendors take advantage of variations in transit agency needs and tastes.
- *New technology insertion:* New or innovative technologies that are compatible with a standard interface may be introduced.

At the same time, open system standards may also have significant impacts on vendors and on the APTS industry as a whole. Where there are only a few vendors for a particular product or service, as is often the case in the public transit industry, there are a number of major costs:

- Profit margins for vendors with proprietary or off-the-shelf integrated solutions are likely to decrease, discouraging their acceptance and use of the standard.
- Standards often inhibit innovation for technologies that are defined within the standard. That is, they "lock in" particular technologies, and such choices are often difficult to change. In addition, they may eliminate other cost-effective or technically superior options (e.g. other emerging technologies, gateways, etc.).

Specifically in the transit industry, there are several markets where there may be significant dis-benefits (or costs) of standards for vendors. This is true for technologies such as radio systems and electronic fareboxes, where either: (1) there are only a small number of vendors, leading to heavy competition for market share but little choice for transit agencies; or, (2) proprietary products and interfaces that are sold only as part of a more comprehensive, but not modular, package.

4.2 Vendor Survey

To explore the state of the practice among vendors, and to explore their beliefs about interface standards for their products, a survey of advanced technology vendors was conducted. Using a variety of public sources, about 300 firms were identified, both within the U.S. and internationally, with APTS-related products. A short questionnaire was sent to these vendors, asking for the following information:

1. Summary information about the size of the firm (number of employees, revenues, etc.) and the percentage of its business that is focused on the public transit industry;
2. A brief description of their product(s) for transit agencies;
3. The types of data formats and data transfer protocols (communication rules) used as input to and/or output from their product(s); and,
4. The types of data formats and data transfer protocols for any interfaces between sub-components within their product(s).

A copy of this survey is included as Appendix B. The results of the survey responses are as follows. Of the firms who received surveys, 33 responded, although only 27 of those responses were deemed usable for a majority of the questions in the survey. This gave a response rate of about **9%,** which is generally poor and leads one to be suspicious of the biases that are inherent in such a small sample. *For this reason, the results presented here should be viewed with healthy skepticism.*

Of the 27 companies with useful responses, 20 have headquarters in the U.S. with the remainder in Canada and Europe. 13 vendors (just under half) have 100% of their transit products manufactured in the U.S., with five additional vendors that produce a majority (50% or more) of their products in the U.S. Of the 27 respondents, 8 have been selling products for the transit industry for 5 years or less, 8 more from 5 to 10 years, and 5 more between 10 and 20 years in the business (leaving only **6** that have been serving the transit industry for more than 20 years).

These 27 vendors reported a total of 32 products; most vendors simply reported only on a single product, although they were asked about all their transit products. The vendors were asked to describe the products using the following classification scheme, depending on where the hardware, software or communication system was most likely to be used at a transit agency. This was done to help identify what interfaces might be relevant for each product.

- On-Vehicle - Products that are used inside transit vehicles (such as GPS receiver, fare box).
- Operation Center - Products used in operation centers and dispatching (such as computer-aided dispatching, driver and vehicle logs).
- Communications - Products used to provide communications between different units within the transit system (Such as mobile radio, cellular service).
- Planning, Management and Administration - Hardware, software, and related products used for management, administration, planning and financing of a transit agency (such as Geographic Information Systems, Management Information Systems).
- Roadside and In-Stop - Products utilized along the transit route, and inside bus stops and rail stations (such as information kiosk, signal priority devices, and passenger information signs).

The survey allowed vendors to identify multiple categories for each product. Of the **32** products, 15 had on-vehicle components; 4 had components for operations centers; 5 had components for communications; 11 had hardware and software for planning, management and administration; and, *2* had devices for roadside and in-stop locations.

The survey also asked vendors to identify whether they worked collaboratively with other companies or with any transit agencies in the development or production of the product. About 56%, or 18 of 32 products, had been developed collaboratively; this at least suggests that some of the products are enhanced through integration with other firms' products. Also, 19 of the ***32*** products were said to conform to some published standards, suggesting that vendors are aware of, and to some extent using, existing standards for hardware, software and communications.

Of more direct relevance to this report are the data formats and interfaces from their products. The survey asked the vendors whether they considered the interfaces from their product to be open orproprietary, with the following definitions:

- Open data formats are those formats that are described in technical documentation that is publicly or commercially available.
- Proprietary data formats, on the other hand, are those not described in publicly or commercially available documentation.

Vendors were asked to describe their products in terms of whether all of the data, some of the data, or none of the data are in an open format. The results, broken out by product category, are shown in Table 4-1. In about two-thirds of the on-vehicle products, there are open data formats, although several (four) of the products had no open interfaces; these included electronic fareboxes and security monitors. Much of the software for planning, management and administration, as well as more comprehensive systems that covered several product categories, have at least some open interfaces. The exceptions include accounting and financial software and proprietary communications services (paging). From these responses, it appears that one challenge to open interfaces are security-critical (financial and safety-related) services.

Table 4-1: Product Data Format Descriptions

Product Category	All Open Formats	Some Open Formats	No Open Formats
On Vehicle	2	6	4
Operations Center / Dispatch	--	1	--
Communications	--	--	--
Planning, Management and Administration	4	1	2
Roadside and In-Stop	--	1	--
Multiple categories	4	4	1

ote: Total of 30 product responses.

For these responses, the survey then asked each vendor to identify benefits they received from the selected data formats, whether open or proprietary. These results are shown in Tables 4-2 and 4-3 for open and proprietary data formats, respectively. The most common benefit identified for having open data formats is a larger market due to interfacing with other company's products, which was identified for 17 (about 90%) of the 19 products with at least some open data formats. This suggests that vendors widely believe that interface standards will enhance their business market. Other benefits, such as a lower probability of product obsolescence, and lower development costs, were cited less often but are still significant.

The benefits identified for proprietary data formats are shown in Table 4-3. The most noted reason (mentioned for 14 of 16 products with proprietary data formats) was the ability to customize the product to meet the needs of the individual customer. Customization is often needed for products, and the need for open data formats is not as compelling, since inter-operability is naturally limited by the customization. Vendors listed 11 products that benefit from

Table 4-2: Benefits of Open Data Formats

Type of Benefit	Number of Products
Larger market due to ability to interface with other company's products	17
Less chance that the product will become obsolete	10
Lower development costs related to the data formats	8
Other - Better flexibility	1
Other - Often a pre-requisite	1
Other - Easy integration with other suppliers	1
Other - Not useful to the customer	1
Other - Use of other data on bus	1

Note: Multiple answers are possible for a given product; there were 19 product responses.

Table 4-3: Benefits of Proprietary Data Formats

Type of Benefit	Number of Products
Cheaper to produce product	**7**
Better revenue potential	4
Maintain product market share	8
Ability to control design	**9**
Product fits easily into a large system our company produces	11
Better able to tailor product to individual customer's needs	14
Other - Safety	1
Other - Performance	1

Note: Multiple answers are possible for a given product; there were 16 product responses.

proprietary standards because they fit more easily into a comprehensive system. Also, over half of the products mentioned that the control of system design was an important benefit of proprietary data formats. Fewer vendors identified cheaper production costs, better revenue potential, or market share arguments as notable benefits of proprietary data formats. These findings suggest that, among other things, the demands of transit agencies for customized hardware, software and communications provide one good reason for vendors to keep proprietary data formats. Also, while system integration is an important driver toward open data formats, it also can be used as a compelling argument for a particular vendor to provide their own comprehensive, but proprietary, system. Costs, on the other hand, are not the most important drivers in the selection of proprietary data formats.

Finally, the survey also asked whether vendors (1) had been asked by transit agencies to develop open data formats and data transfer protocols, and (2) would be interested in participating materially (time and/or financially) in the development of these standards in the future. Responses to these questions are identified in Table 4-4 and are cross-tabulated with the status of data formats for their current product. Surprisingly, vendors report that they have only received inquiries about developing open data formats for half of the products (15 of 30). This simple result suggests that if transit agencies are interested in open data formats for a broader range of information technologies, there is still a need to communicate these needs and interests to many vendors. Second, for about 60% of the products (18 of 30), vendors are interested in participating in standards development. This seems to indicate that there is substantial support among transit vendors for the development of open data formats.

Also in Table 4-4, it is interesting to note differences between those who have received requests for open data formats and those interested in participating in standards development. For 11 of 30 products (37%), the vendors are aware of the needs of transit agencies and are eager to participate in standards efforts. An additional 7 out of 30 (23%) have not received these requests but are interested in pursuing these standards anyway. Interestingly, for 4 products, the vendors had received requests for open data formats but have no interest in developing these

Table 4-4: Vendor Interest in Standards Development

For this product, ...		Current Interfaces		
Has your company received inquiries about developing open data formats / transfer protocols?	Is your company interested in participating materially to develop industry-wide standards?	Open	Open	Open
Yes	Yes	6	5	--
Yes	No	--	2	2
No	Yes	3	1	3
No	No	1	5	2

Note: Total of 30 product responses.

standards. For **8** products, the vendors are content without industry standards, and have not received any request for open data formats. These results suggest that a majority of transit product vendors would be willing to participate in standards development efforts, but perhaps need to be plugged into the work now in progress (i.e., TCIP). It also suggests that there are some vendors who will not come to the table of standards development on their own, but are more likely to do so if transit agencies ask more directly for open interface standards.

5 Case Studies of APTS Functions and Interfaces

5.1 Introduction

This chapter examines the experience of several agencies developing APTS-related applications. In light of the previous arguments about possible benefits and costs of interface standards, several case studies were selected to illuminate issues associated with systems integration, architecture and interface standards. Four recent projects were selected: (1) the Bay Area Transit Information Project; (2) the Metropolitan Transportation Commission's TransLink program; (3) system integration for the OUTREACH paratransit service in Santa Clara County; and, (4) the Bay Area Rapid Transit (BART) NXTGEN project. Each of these projects is described separately in this chapter. The description includes an interpretation of the project using the architecture from Chapter 3 and additional observations on the technology development process at each site.

5.2 Bay Area Transit Information Project

The Bay Area Transit Information Project (BATIP) is an Internet site that provides transit information for all of the major transit agencies in the greater San Francisco Bay Area. With 23 transit agencies in the Bay Area, gathering pertinent information can be very difficult, especially in planning trips that use several agencies. The BATIP was designed to provide a common, Internet-based source of accurate transit route and schedule information.

A more complete description and history of the BATIP is given by Gildea and Sheikh (1996). The Bay Area Transit Information Project was started in May of 1994 as an independent volunteer effort to make Bay Area transit information available to the public through the emerging technology of the World Wide Web. Technically, the project has evolved from an informal Web site located on a server owned by a UC Berkeley student to a formal Web site supported on a workstation by the Bay Area Rapid Transit District. It is important to note that the technical development of the BATIP has followed that of the World Wide Web very closely: the Web was largely in its infancy in early 1994, and the creators of the BATIP were using software and Internet tools that were largely unproved and not widely accepted at the time.

As shown in Figure 5-1,[7] the information flows in the BATIP include several electronic interfaces, requiring accepted data formats and communication protocols. First, any person can access the information from a computer and a modem (i.e., through a device acting as the PIA or RTS subsystem) with Internet access and an Internet browser. A request can be sent for the information directly over the Internet, with a forthcoming response. The traveler information is made available through a server connected to the World Wide Web (here, acting as the ISP). The World Wide Web functions using a standard communication protocol known as Hypertext Transfer Protocol (HTTP), and documents are transferred in a standard language called Hypertext Markup Language (HTML). HTML has become very popular because it allows formatting text, using graphics, providing links and implementing fill-out forms in a convenient manner. Both HTTP and HTML are *de facto* standards for formatting and transmitting data over the World Wide Web.

Route, schedule and fare information is provided to the BATIP by the transit operators.

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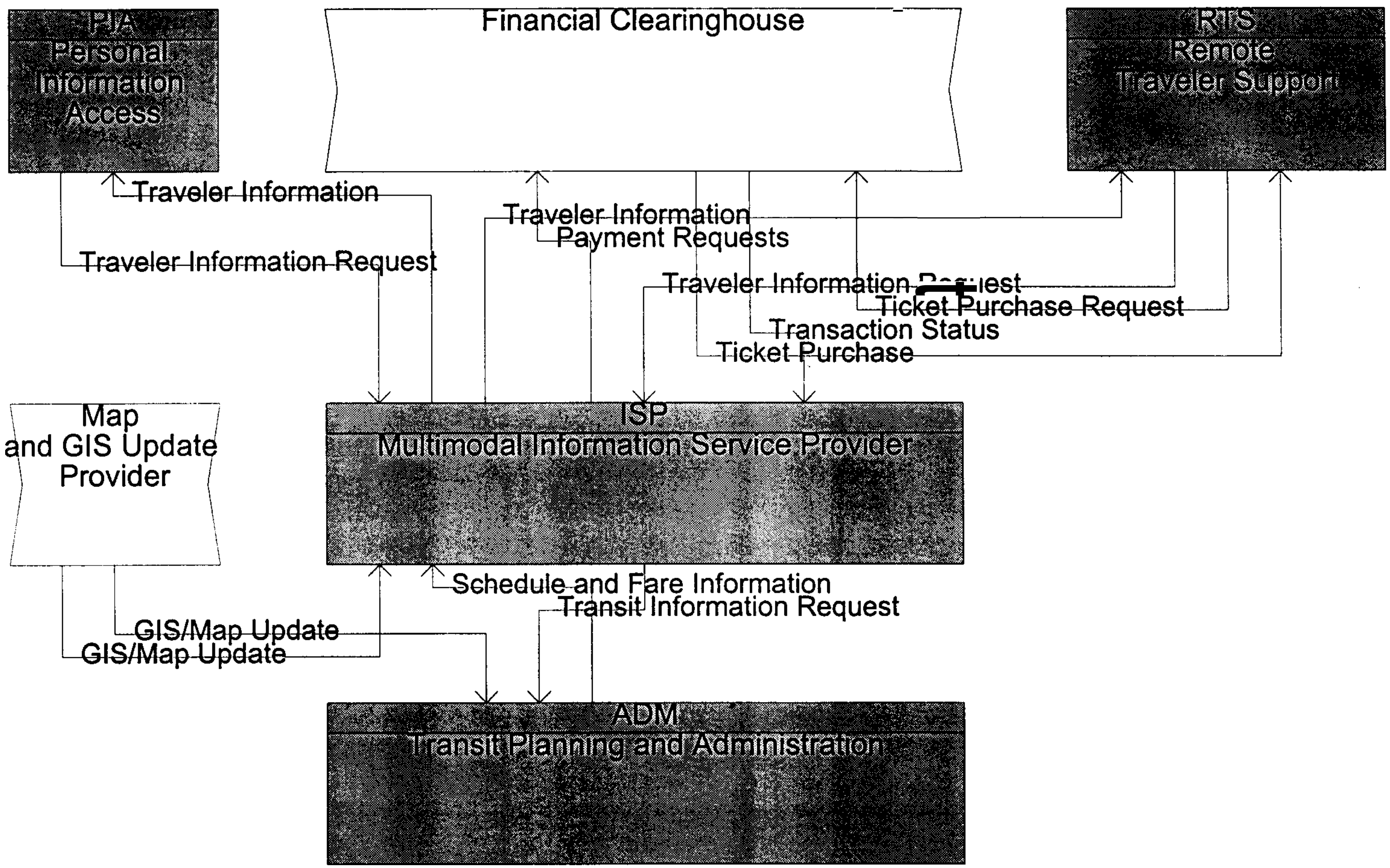
[7]The notation from Chapter 3 is used extensively in this text.

Figure 5-1: Architecture Flows for the Bay Area Transit Information Project



Here, this indicates that various transit agencies (ADM) are passing schedule and fare information to the Web server (ISP) run by the BATIP. In the beginning of the BATIP project this information was entered manually from existing published schedules; now all information is transferred electronically either through modem or on diskette. The larger transit agencies in the region use agency-specific scheduling software, and can provide their information in established text formats such as MS Word or ASCII. Smaller agencies more often use spreadsheet software packages for their scheduling and provide their schedules in that format. Thus, the BATIP is able to accept this information in virtually any format provided by the transit agencies.

Since the route and schedule information from transit agencies comes in a variety of formats, the system operators have written software to convert all incoming information into ASCII text. For the Web server, although the header and footer for all the pages are in HTML, the schedule information is left in an ASCII text file on the server. Each time the information is called by a user, the relevant information is loaded and converted into HTML for display. Although this process slows down the loading time, it makes adding and updating the information much easier.

Most agencies have route or service area maps in Adobe Illustrator, Page Maker or PostScript formats which they use for their customer maps and brochures. These maps are made available to BATIP; hence, the connection from the Map and GIS Update Provider to the ISP in Figure 5-1). However, these maps must be converted electronically to the GIF (Graphic Interchange Format) in order to be used on the Web site. Like the schedules, the developers have software to convert the maps to GIF for the Web site.

Optimistically (in an ideal world) in the future, this information might be provided at a fee, or fare transactions and trip reservations might be accommodated directly over the Web server. In such a case, the server (ISP) would also need to communicate with a financial clearinghouse (FCH) to share fare and payment information. More on this subject is described in the TransLink project in Section 5.3.

In summary, the development of the BATIP project was aided by the existence of *defacto* World Wide Web interface standards such as HTTP and HTML. The existence of these established standards make the information provided by BATIP easily available to anyone who has access to the Internet. Also, both established and *defacto* data format standards such as ASCII, MS Word, spreadsheet applications, and GIF are used in transferring data to the BATIP Web site. In this way, the information provided to the BATIP developers by the transit agencies is already in well-established data formats (although not completely “open” or non-proprietary). In this case, the developers were able to recognize the potential of the World Wide Web for information dissemination, and gambled on the emerging *defacto* standards of HTTP and HTML for developing their Web information.

5.3 TransLink

The Metropolitan Transportation Commission (MTC) initiated the TransLink Program in 1992 to develop a more universal fare media for the Bay Area. Financial support is provided by the Federal Transit Administration (FTA), but it is important to note that the project is funded under Section 9 of the Federal Transit Act. (i.e., it is not an ITS set-aside). Phase I of the TransLink project was a demonstration between the Bay Area Rapid Transit (BART) District and County Connection, the transit operator in central Contra Costa County. This demonstration, which ran from May 1993 to September 1994, involved the use of a paper-based magnetic stripe card at BART rail stations and on board BART Express and County Connection busses. While the feasibility of the paper magnetic stripe cards was proven, the technology did prove to have considerable reliability problems. In addition, for this limited trial, most users of the fare card were consistent BART riders, while very few bus-only riders used the fare media. The final evaluation (Mundle and Associates, 1995) recommended consideration of a fare media that could be both more reliable and more universally accepted across many transit agencies.

The MTC then funded a study to examine alternate media and methods of accounting for fare transactions. The technology choice that emerged is a credit-based or debit-based “smart card”: a small wallet-sized card that contains a integrated circuit (IC) chip and an interface to allow read and write capabilities. Based on this technology, the MTC sought answers to several more obvious questions regarding the fare transactions, including: (1) What type of technology would be most appropriate? (2) To what extent would third parties be involved in the distribution, management, and accounting under this system? **(3)** How would income from the fare transactions be distributed to the various transit agencies? and, (4) What information systems would be necessary to track these transactions? The final study report (Benton International, 1995) proposed that an operational clearinghouse be established to manage financial transactions from the TransLink service.

The MTC is currently proceeding with Phase II of the TransLink project, implementing a common fare instrument for 7 major operators in the Bay Area, with actually field testing of equipment for 6 months. The primary goals of this demonstration are to: (1) clarify institutional roles in implementing TransLink, including sales, distribution, operations and management; **(2)**

develop a clearinghouse for managing financial transactions; and (3) evaluate the public acceptance, technical feasibility, and cost-effectiveness of the chosen fare payment technology. It is important to realize that, while identified as a demonstration, the Phase II effort is clearly intended to be a long-term investment in the technology and institutional relationships.

There are still several important technical challenges for the TransLink project, including the choice of fare media. Options include:

- **A** plastic magnetic stripe card, similar to credit cards or automated teller machine (ATM) cards.
- **A** "contact" card, with a built-in IC chip but which requires physical contact with a reader to complete a transaction.
- **A** "contactless" card with a built-in IC chip that is able to read and write using high-frequency radio transmissions with a reader.
- **A** "combination" card (or "combi-card") that includes both the contact and contactless means of conducting transactions.

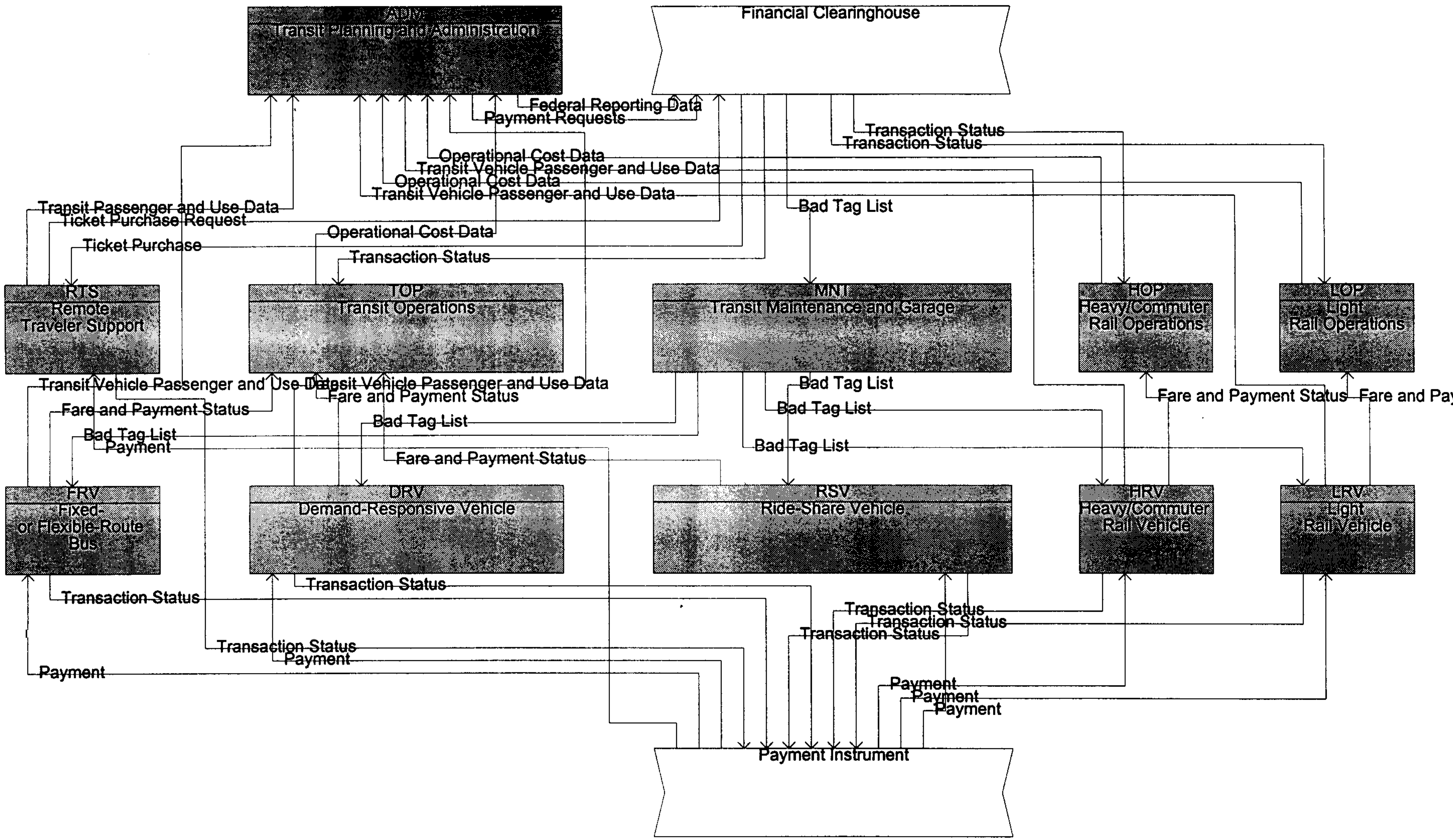
The magnetic stripe card has several flaws, both for technical and institutional reasons. Perhaps of greatest concern of magnetic strip cards is the harsh environment of the transit bus for card readers requiring physical contact. Standards for a contact card are fairly well-established (ISO 7816), but the current standard leaves considerable room for interpretation: there are at least two competing interpretations of the standard. While the suitability of the ISO 7816 standard could be questioned, the underlying dilemma of physical contact with a reader is still problematic for transit applications. For the contactless and combi-card, draft standards are being developed. The contactless card has a draft standard under ISO 10536, and the MTC hopes to use this draft standard in an RFP for Phase II. The combi-card, perhaps a preferable option in the long run, will likely have a draft standard in early 1998.

Figure 5-2 shows the context of information flows that are likely to be necessary for the TransLink program. From the bottom of the figure, the TransLink payment instrument would need to interface with readers on board any type of transit vehicle (bus - FRV, demand-responsive van - DRV, ride-share car or van - RSV, and possibly rail vehicles - LRV and HRV) as well as with remote card readers (RTS). Communicated data would include payment and transaction status. "Hot" tags and identification numbers (i.e., a "Bad tag list") would also need to be communicated to these readers, in order to ensure security and to avoid fraudulent use of the payment instrument.

Passenger payment, vehicle usage and card usage data would then be communicated from these vehicles and the remote site to transit operations and/or to transit management. This would indicate passenger loads, use of the fare instrument, revenues to be collected, and some operational data on passenger demand. This is indicated in Figure 5-2 as data that flows from the various transit vehicles and RTS to transit operations centers, and on to transit administration (ADM). Transit administration in turn can use this information to estimate revenues and other measures of consumption, such as passenger miles, passenger trips, etc. that are required for Federal reporting requirements.

In addition to these interfaces, there is a need for communication of transaction information to a financial clearinghouse, which could either be within the transit agency or reside with a third party. This interface would include communication of (1) card purchase, validation and addition of value; (2) transaction and account information; and, (3) a "hot list" or "black list" containing unacceptable or invalid cards or accounts. Of course, these transmissions must be secure in the electronic sense. Currently, a wide variety of secure electronic payment protocols do exist and

Figure 5-2: Architecture Flows for the TransLink Project



are in widespread use. In addition, a “hot list” or “black list” of accounts or card identification numbers would need to be transmitted on a regular basis from the clearinghouse to the card readers, through some common link (here indicated as a server within the transit garage or maintenance facility, MNT). It is important to note that, in the TransLink project, the MTC is acting in a management role, administering and overseeing the contract, but providing no direct communication or data processing link in the architecture.

In summary, the financial industry has been aggressively pursuing electronic transaction standards over the past several years. As a result, many of the information flows within the TransLink architecture specified above are either existing or soon-to-be draft standards. The development of a contactless card standard, at least in draft form, will allow the MTC to incorporate such a standard for readers, cards, and radio frequency (RF) communication directly Moreover, to a large extent, the MTC hopes to leverage existing financial transaction standards for data communication and exchange between each transit agency and the TransLink Clearinghouse. It appears that the existence and emergence of these standards have certainly facilitated the progress to date in moving toward Phase II of TransLink.

At the same time, the lack of existing specifications for an architecture to handle fare transactions from card readers to and through each transit agency are sticking points in the technical development of Phase 11. Because the existing vendors of transit electronic fare collection systems use proprietary data formats and transfer protocols, there is no open system standard or specification to date. This means that the TransLink program, in concert with the stated needs of the many transit agencies in the Bay Area, will have to develop these specifications, significantly delaying the development and release of an RFP for Phase 11.

5.4 System Integration within the SMART Demonstration at OUTREACH

OUTREACH serves as the broker of paratransit services in Santa Clara County, California, under contract to the Santa Clara Valley Transit Agency (VTA). As a nonprofit agency, OUTREACH serves as the key administrative and managerial support for door-to-door transit services for the elderly and disabled, primarily for those certified for service under the Americans with Disabilities Act (ADA). OUTREACH contracts with several private van operators, totaling about 150 vehicles (vans) providing door-to-door travel within the VTA service area, and providing about 1800 trips per day.

In 1993, in an effort to expand service and increase effectiveness of service delivery, OUTREACH developed the SMART paratransit demonstration project (hereafter called SMART). The basic idea behind SMART is to provide real-time service monitoring capabilities at OUTREACH. Significant technical elements to meet this objective include:

- An automated vehicle location (AVL) system having the capability to track van movements in real time and provide van drivers with key trip information in real time;
- Digital radio communication to transfer data between the vans and the OUTREACH offices;
- Mobile Data Terminals (MDTs) in the vans to display real-time schedule information;
- A digital map database to provide a geographic (map) reference for pick-up and drop-off addresses, and to display current van locations; and,
- Software to provide schedule and routing information to van drivers and dispatchers, and to the trip coordinators at OUTREACH.

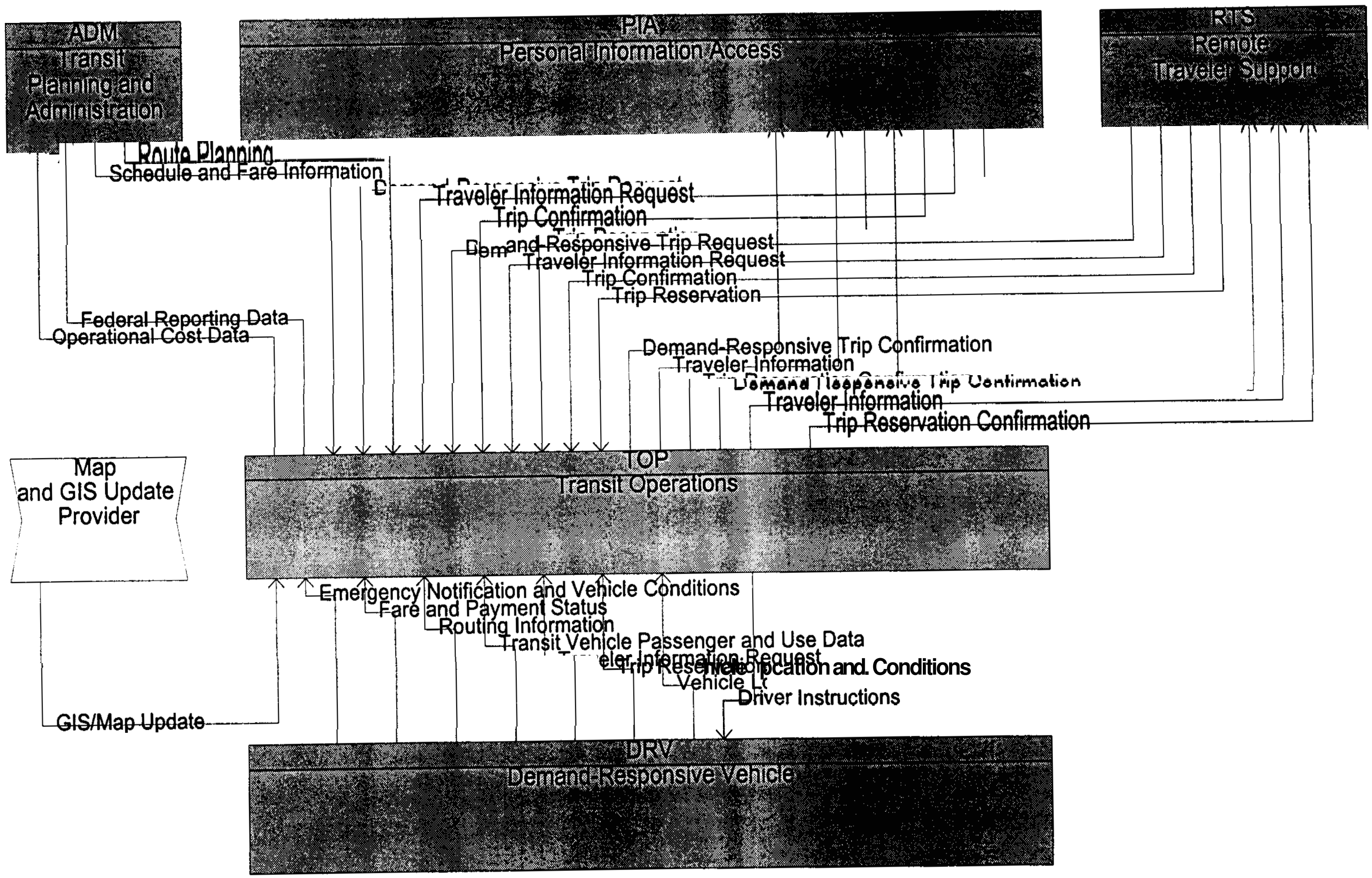
The SMART project officially began in April 1994. Phases I and II of the project involved securing and customizing the digital map database and integrating that information into new commercial off-the-shelf (COTS) paratransit scheduling and routing software. These elements were on line as of February 1995. Since that time, OUTREACH has secured additional radio frequency spectrum to communicate digital data between vehicles and the central office. Also, mobile data terminals (MDTs) were placed in 40 vans (across three private operators), and global positioning system (GPS) satellite signal receivers were placed in each of these vehicles to track their location. All of the technical systems were fully installed by the fall of 1996, with a formal project unveiling in January 1997. A more detailed description of the project and the technical architecture is given by Chira-Chavala et al. (1997).

It is of particular note that all the technical components were novel to OUTREACH, and as an integrated set were new to the paratransit industry in the U.S. This had several implications. First, the new systems were intended to replace completely the existing manual methods, and as such were intended to be a long-standing commitment to these technologies. Second, because these technologies had not been linked before at a paratransit agency, there was considerable need for system integration. There was thus a strong element of "learning by doing" as part of this demonstration, with a commitment to finding long-term technical solutions.

It is also of note that the responsibility for technical systems integration was borne by the suppliers themselves. As shown in Figure 5-3, this involved several important interfaces in the SMART project:

- Standard paratransit software **features**. The main role of the computer-aided scheduling and dispatch system at OUTREACH is to take requests from customers either over the telephone (PIA) or from other remote sites (RTS). These trips are requested and confirmed during the same session, so that the customer gets immediate confirmation of their trip.

Figure 5-3: Architecture Flows for the SMART Project



- **Connecting the MDT system with the scheduling software.** While the MDTs were an off-the shelf system, custom changes in the MDT viewing screen were necessary to accommodate the scheduling software. Also, a separate "MDT server" at OUTREACH takes information on the next 6 pick-up and drop-off locations for each vehicle from the scheduling software. The server automatically generates messages for the van MDTs and transmits these over the AVL communication link. This is represented as the communication of "Routing Information" and "Driver Instructions" between transit operations (TOP) and the vehicle (DRV) in Figure *5-3*. Once these data are downloaded to the MDT, they can be viewed by the driver.
- **Geographic data referencing.** The digital map database was used as the common geographic referencing scheme in both the AVL and the paratransit scheduling software, as shown in the figure. Although the map database is proprietary, its contents can be exported into appropriate formats for other applications.
- **Connecting the AVL and mapping software with the scheduling software.** The scheduling software and client database are available to *both* the OUTREACH ride coordinators, as well as to the private van dispatchers through (read-only) remote terminals. (This is done completely within transit operations in figure *5-3)*. It was also desired that both the OUTREACH ride coordinators and van dispatchers have access to the AVL data, especially access to a map showing real-time vehicle locations. To achieve this, additional software was added to the MDT server to accept real-time location information from the AVL system.
- **System monitoring, management and performance reporting.** According to

OUTREACH personnel, one of the more difficult issues confronting the SMART project was designing effective system monitoring and reporting. This involved the communication of important data from transit operations (TOP) to planning and administration (ADM). The evaluation and reporting requirements from this project came from various sources, including the project sponsors, the implementers, and the evaluators. The definitions of particular data and performance measures, even as basic as a “rider,” a “passenger trip” or a “revenue vehicle mile” were not crisply defined for paratransit. As such, it was difficult in the SMART project to get the various oversight agencies and the scheduling software vendor to agree on data definitions. Moreover, once such measures were defined, custom software was needed to generate the appropriate measures (Chira-Chavala and Venter, **1996).**

Hence, there was a fair amount of customization to meet the unique technical requirements of this project. In these cases, standards would clearly have made a difference in the cost of integration:

- The interface between the scheduling software and the MDTs required significant customization of software at the control center and of the MDT hardware on board the vans.
- The interface between the original AVL mapping software and that of the scheduling software required considerable new code (software) and hardware for integration.
- The format and content of management reports required significant customization. Simply to agree on common data items and their definitions required significant effort by personnel at OUTREACH and at the scheduling software vendor.

The lack of standards to integrate scheduling software, AVL and MDT systems in the SMART project is explained in part because the project was the first to implement such an system. **As** such, the paratransit industry and the product vendors had not really seen the need in the past to develop such standards.

Perhaps less easily understood, however, was the level of effort required to produce meaningful management reports based on the trip logs and real-time service monitoring within the scheduling software. It is believed that the current performance measures, based on Section 15 requirements, are (1) not crisply defined, and (2) not meaningful for hands-on management and monitoring of day-to-day service provision. Unfortunately, to date, the paratransit industry as a whole has not been effective in articulating specifications for performance monitoring. In the SMART project, this resulted in substantial cost for custom software.

An element of "learning by doing" came in the evolution of system specifications where none existed before. Standards for data definitions and interfaces were, perhaps understandably, non-existent when the project began in 1993. This lack of standards meant that technical system specifications were naturally somewhat fuzzy and fluid at the beginning of the project. Moreover, it was only clear what these specifications should be after considerable working experience: it was only during more technical discussions of the emerging system that OUTREACH was able to identify and articulate specific technical needs and requirements.

5.5 Bay Area Rapid Transit (BART) NXTGEN Project

The $40 Million NXTGEN project at BART will replace three current computer systems which handle train control, fare collection, and station message signs individually. Currently, each system consists of different, independent computers in BART's Central Control and at individual stations. However, under NXTGEN, all these functions will be performed on a common fault tolerant computer platform at Central Control and in each station (BART, 1995). The project was started in 1992 and is scheduled to be completed in late 1997.

BART first began operations in September of 1972. At the time, BART computer system was considered state-of-the-art. However over the years, the system has become obsolete. Major service extensions over the past few years has prompted BART officials to initiate the NXTGEN project. NXTGEN was mainly stimulated because:

- BART is adding 35 miles of track and 5 new stations now, and is anticipating more extensions.
- The existing system cannot operate reliably for 24 hours per day
- Maintenance costs were rapidly increasing due to frequent break-downs and unavailability of parts.
- The original software was written in Assembly code by contractors in 1960's. **As** such, the program could not be easily modified for new purposes or requirements.

The main goal of NXTGEN is to combine several functions into one system by moving from an obsolete proprietary system to an open, fault-tolerant, network-based environment (BART, 1995). The NXTGEN architecture is an open system, which uses vendor-independent standards to allow maximum flexibility in extending, upgrading, and evolving the system. The open architecture standards include the fault tolerant operating systems, programming language, communications and network management protocols. The open standards architecture also enables BART to purchase off-the-shelf products instead of specialty products. Particular elements of NXTGEN are discussed below.

- **Network:** The NXTGEN architecture is based on several local area networks (LANs) connected to form an extended enterprise wide area network (WAN). The computer hardware includes redundant inter-connections to the LANs and WAN, with ethernet-based routing and bridging LAN connectors. The network uses the TCP/IP (Transport Communication Protocol/Internet Protocol) communications, and Simple Network Management Protocol (**SNMP**) for network management. The fault tolerant computers support both of these protocols.

- **Remote Site Computers:** A fault-tolerant computer will be placed in each remote site or station, and will operate unattended. At each site, the LAN connects the remote computer to the automatic fare collection (AFC) equipment, the announcement system, destination signs, plant interface system, and human interface equipment. Thus each remote site fault-tolerant computer will perform the following functions:

    - Managing the LAN
    - Automatic fare collection and data acquisition
    - Destination sign management
    - Train information monitor management
    - Automatic announcement management
    - Non-vital automatic train operations (planned in the future)
    - Forward information through the WAN to Central Control

- **Central Control:** The central control fault-tolerant computer will be located at the BART central site and will host the central control LAN. It will contain the Central Control System (CCS) software and the central portion of other applications. Through the central control LAN, the central control fault-tolerant computer performs the following functions:

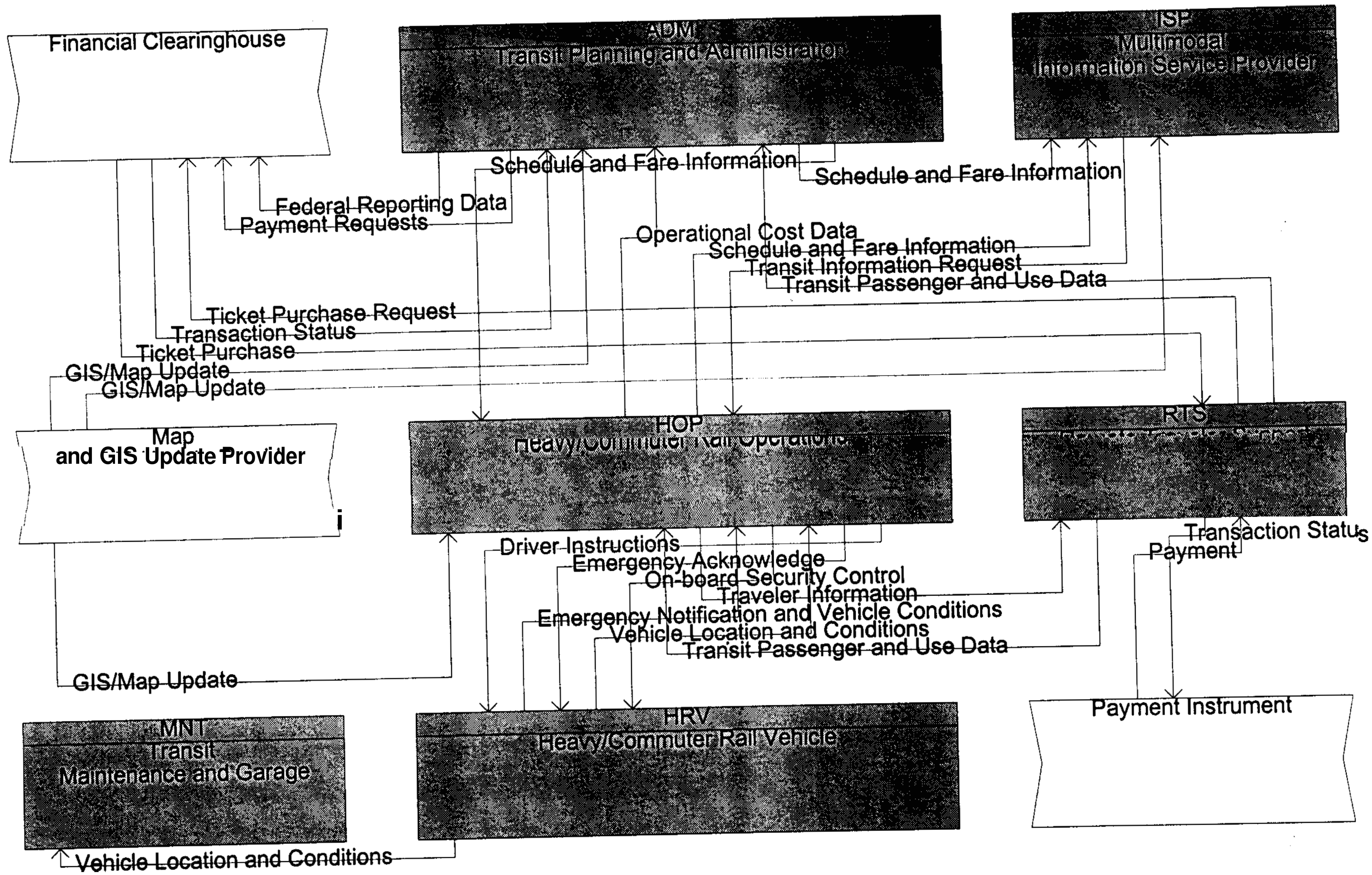
    - Receive commands from the central control staff through the controller consoles.
    - Receive information and issue commands to remote site fault-tolerant computers.
    - Prepare and display graphic information regarding trains and equipment to central

control staff
    - Train supervision
    - Electrification and support system supervision

- **Automated Fare Collection System:** The software for the fare collection connects all of BART's ticket vending machines and gates with a central computer, allowing immediate control of each machine and providing accurate real-time data on every single ticket (Wolinsky, 1994). BART staff can monitor the fare collection system through a standardized X-Window (X-11) graphic user interface. The interface is designed so that BART staff can operate the complex network without extensive training. Security measures have been build in to limit information to authorized personnel only.
- **Automated Train Control System:** BART's current train control system consists of track circuits to locate trains. This information is then sent to Central Control (CCS) for processing. Based on schedule and safety requirements, CCS automatically determines the appropriate speed, and transmits it to the train. In this way, CCS is responsible for all aspects of train control. BART is currently planning to replace the current train location system with a modified GPS system, with transceivers on each car pinpointing the exact length and location of the vehicle. Since the current system can only report the location of the head of the train, the new system will allow BART to run trains at closer headways and thus increase capacity of the system.

Figure 5-4 shows the information flows for BART's NXTGEN project. Because continuous communication is needed for the automatic train control system, vehicle location and status information must flow from the vehicle (HRV) to the CCS (HOP), and both vehicle commands

Figure 5-4: Architecture Flows for the NXTGEN Project



and driver instructions must be communicated from the central control to the vehicle. In addition, the new NXTGEN system includes communication of vehicle status directly with BART maintenance. The tasks of automating fare collection, using either the current BART magnetic strip card or other media, is conducted at the various station locations (Payment Instrument to and from the RTS). Those data are communicated to transit operations to monitor transit demand, and is communicated to planning and a financial clearinghouse (within BART) to manage these transactions.

Current schedule and real-time train arrival information is also managed within the NXTGEN project, as train schedules and arrivals at stations are computed and communicated from the CCS (HOP) to passengers on each platform (as an element of an RTS). Current schedule, fare, and map information are communicated to information providers (such as BATIP). Also, BART has an on-line itinerary planner through BATIP that allows one to use a digitized map to determine shortest routes and schedules between any two stations in the BART system (hence the connection fi-om the Map and GIS Update Provider to the ISP in Figure 5-4).

According to BART staff, BART adopted an open system and conformed to existing standards for the following reasons:

- To be independent of specific hardware and software vendors.
- Have the ability to competitively bid each part of the system now and for any future expansions or additions.
- Future additions to system can be done with little or no modification to current software.
- Availability of graphical user interface.
- Capitalize on commercially available software and communications drivers, thus cutting research and development cost.
- Increase the pool of available technical staff through using more common and less complicated systems.

In addition, the fault tolerant environment has enabled BART to

- Minimize downtime to a maximum allowable downtime of less than 5 minutes.
- Computerize most functions, thus minimizing human interaction with the system.
- Operate continuously 24 hours a day, 365 days a year.
- Improve reliability by decentralizing train and other system control across the whole system

The fault-tolerant open system will allow BART to save on operating costs. BART officials believe that NXTGEN will reduce their maintenance costs by as much as 30%, and increase the availability of the system from 95 % to 99.98 %.

Once NXTGEN is implemented, BART will become world's first public transit agency to adopt a completely open and fault-tolerant architecture. BART's existing proprietary system was becoming increasingly obsolete and expensive to maintain. Through NXTGEN, BART officials hope to simplify the operation of a system that is becoming increasingly more complex. Also, by adopting an open system, it is believed that future expansions to the system will become much more easier and less costly to implement. Although the initial costs of implementing NXTGEN are rather high, it is expected that the savings in daily operations cost, and higher productivity of the system will pay for the project in less than five years.

6 Conclusions and Recommendations

6.1 Conclusions

The underlying purpose of this study has been to identify under of circumstances interface standards can be beneficial to the transit industry. Specifically, the goals for the study were:

1. To provide a consistent and logical framework for assessing the technical requirements of APTS services, including: functional requirements, data needs, potential data sources, and interfaces between different technologies to identify system compatibility;

2. To provide useful guidance to transit agencies to plan for and develop their information technologies; and,

3. To provide critical raw material to the TCIP and TC204 Working Group **8** about the possible uses of the products from the national ITS architecture program.

The transit architecture described in Chapters 2 and **3** provides both the framework described in the first point and the raw material desired from point 3. Moreover, in terms of implementing the architecture and related standards, the existing literature, the vendor survey and the case studies suggest several critical factors that affect the benefits from such interface specifications.

A structured view of transit data flows, messages, and interface protocols is necessary. The development of APTS technologies requires a rigorous definition of data elements, data transfer protocols, and message sets. To date, a rigorous systems analysis of these requirements is lacking. While the efforts of the National ITS Architecture and the TCIP are formulating more rigorous object and message set definitions, there is still much to be learned from both a "top-down" and a "bottom-up" review of transit interface requirements. Specifically, the formal subsystem and architecture flows defined in this project, and that are defined to date by the National ITS Architecture and by the TCIP, are still not sufficiently detailed to provide much assistance in helping transit agencies generate technical specifications for APTS systems.

It is widely believed that interface standards will be valuable to transit agencies. While there is little quantitative evidence to date, the efforts of Sandia National Labs, the National ITS Architecture, and the current TCIP program indicate that there is substantial interest from the public sector (at least the USDOT) in developing and promoting interface standards for the transit industry. Transit agencies themselves are seen as prime beneficiaries, primarily in terms of (1) potential cost savings from more standardized products, and **(2)** enhanced inter-operability of products.

Vendors have competing interests in development of interface standards. The literature review and vendor survey suggest that the primary benefit to vendors of open interface standards is the access to larger markets afforded by inter-operability. Cost savings or revenue gains are cited less frequently by vendors. At the same time, transit agencies often request systems that are (1) customized based on particular needs or requirements at each agency, and/or (2) part of a more comprehensive (but not necessarily modular) system. The vendor survey suggests that these two requirements encourage vendors to develop products using proprietary data formats.

The timing of standards development and market forces are, and must be, closely linked. In several cases, standards development efforts match the growth of a market very closely. In the case of the Bay Area Transit Information Project, the product itself grew in connection with the use of *defacto* standards associated with Web browsers and associated data (HTML) and transfer protocols (HTTP). The second case study, TransLink, identified emerging standards for smart cards and their interfaces, that are evolving as the expected market for smart cards and electronic payment systems is also growing. While TransLink has suffered some delays in waiting for draft standards to emerge, it is believed that the existence of these standards will significantly enhance the long-term viability of the media used for fare collection in TransLink.

Meaningful standards development requires "learning by doing." The third case study at OUTREACH also demonstrates an element of market timing and standards development, but with a different twist. Because the OUTREACH program was one of the first of its kind to integrate the selected technologies, no useful data format and interface standards existed before the project. It was only through the often long and arduous process of bringing OUTREACH staff and vendors to the same table that particular data and system integration requirements were identified. These more detailed discussions, however, are unlikely without the desire and commitment to long-term solutions for technical systems integration.

Constructive dialog between public transit agencies and the vendors is critical. It appears that the TCIP efforts may be more successful in the long run than the National ITS Architecture effort precisely in that both public agencies and vendors are contributing to the discussion, rather than just a single company. The vendor survey also suggests that direct requests (e.g. in technical specifications or in direct communication) from transit agencies for open interfaces may have some influence in the vendors' interest in and development of open interfaces. Also, in both the TransLink and OUTREACH case studies, public agencies took on significant responsibility for bringing both transit agency personnel and vendors into a sustained technical dialog. In these case studies, the perceived benefits of long-term systems integration outweigh the short-term costs of communication to achieve that integration.

6.2 Recommendations for the California Department of Transportation

Based on the observations above, the following recommendations are made to the California Department of Transportation (Caltrans).

- **As** much as possible, Caltrans should financially support the participation of public transit agency personnel to participate in national standards development efforts, such as the TCIP.

As many transit agencies have limited financial resources locally to participate in either regional or national standards development efforts, Caltrans can assist by providing monies for the travel expenses of these individuals who can contribute to these standards development efforts.

- Caltrans should consider carefully the requests for additional funding and delay in the state's APTS-related field operational tests.

Many of California's field operational tests are exploring new technologies and new ways of doing business. By necessity, this will involve a certain amount of "learning by doing." **As** such, these projects may require additional funding and time to produce desirable results.

- Caltrans should provide financial support for technical evaluation of APTS projects in the state.

The development of the APTS projects in the state include many innovative applications of technology (as highlighted in Chapter 5). These applications deserve complete evaluations, which can serve to highlight the technical lessons learned from each project. Specifically, the treatment (use or non-use) of data and interface standards for hardware and software in each project should be evaluated.

- **Inasmuch as California is providing innovative technical research in APTS, Caltrans should promote these technical milestones at the national level.**

Beyond the capabilities of both the local public transit agencies and the evaluators, Caltrans staff and management should take a strong role in identifying important APTS technical contributions from California and promoting these at the national level. This will serve the national standards development process, which desperately needs good, work-able "bottom-up" technical solutions.

- **Caltrans' Office of Public Transportation and Transit California must promote the use of TCIP and similar standards in state-supported transit technology projects.**

It is only as these standards are used in technical specifications that they will be more widely adopted by vendors. Transit agencies within the state need to be made aware of technical standards, and they need to communicate with vendors that they want these standards. Caltrans and Transit California can do their part by educating transit professionals around the state about transit standards such as the TCIP.

References

Bay Area Rapid Transit District (1995), "NXTGEN Computer Architecture," in *Bay Area Rapid Transit Briefing Book,* pp. 9-14 to 9-17.

Benton International, Inc. (1995), "MTC Organizational Plan for the TransLink Clearinghouse," Report to the Metropolitan Transportation Commission (MTC), March 13.

T. Chira-Chavala and C. Venter, "Cost and Productivity Impacts of a "SMART" Paratransit System," Paper presented at the 76th Annual Meeting of the Transportation Research Board, Preprint #97-1366, Washington DC, January 1997.

T. Chira-Chavala, C. Venter, and G. Gosling (1997), "Advanced Paratransit System: ***An*** Application of Digital Map, Automated Vehicle Scheduling and Vehicle Location Systems,'' PATH Research Report, University of California - Berkeley.

D. Gildea and M. Sheikh (1996), "Applications of Technology in Providing Transit Information," Transportation Research Record No. 1521, pp. 71-76.

M. Hickman and T. Day (1996), ***An*** Information and Institutional Inventory of California Transit Agencies, California PATH Research Report, UCB-ITS-PRR-96-12, May.

M. Hickman, **S.** Weissenberger and J. Dahlgren, *Assessing the Benefits of a National ITS Architecture,* Proceedings of the Third World Congress on Intelligent Transnortation Svstems, Orlando, October 1996.

Institute of Transportation Engineers (1996), *Project Plan: Transit Communications Interface Protocol (TCIP)*, ITE-96-02, August 29 (Revised).

Intelligent Transportation Society of America (1994), ITS Architecture Develonment Program: Phase I Summary Report, November.

ITS America APTS Committee, Map and Spatial Database Working Group (1994), APTS Man Database User Requirements Specification, Version 1.0.

Mundle and Associates, Inc. (1995), "TransLink Monitoring Program: Final Report,'' Prepared for the Federal Transit Administration, Report DTUM60-91-C-41020, March.

National ITS Architecture Development Program (1996), *Final Program Documentation.* Prepared for the Federal Highway Administration, United States Department of Transportation, July.

P. Okunieff (1996), *Where in the World is that Bus? and Other Uses for Map Databases in Advanced Public Transportation Systems,* excerpt from Chapter 3 of Institute of Transportation Engineers, Transit / ITS White Paper, Draft of May 21.

PB Farradyne Inc. (1997a), ITS Deployment Guidance for Transit Systems: Executive Edition, Prepared for the Federal Highway Administration, United States Department of Transportation, April.

PB Farradyne Inc. (1997b), ITS Deployment Guidance for Transit Systems: Technical Edition, Prepared for the Federal Highway Administration, United States Department of Transportation, April.

Sandia National Laboratories (1994), IVHS/APTS Information Flow Chart, Version **2.2.**

United States Department of Transportation (1993), IVHS User Service Reauirements, Attachment #6 to the original National ITS Architecture Program Contract, October 13.

L. Wilson (ed.) (1997), Transit ITS Compendium, Published by the Institute of Transportation Engineers, August.

J. Wolinsky (1994), "BART Fare Collection to Earn a Return" in *Railway Gazette International,* May, pp. 315-316.

Appendix A: Proposed Transit Architecture Flows

Source entity	Destination entity	Data flow
MNT	RSV	Bad Tag List
MNT	LRV	Bad Tag List
XFCH	MNT	Bad Tag List
MNT	FRV	Bad Tag List
MNT	DRV	Bad Tag List
MNT	HOV	Bad Tag List
MNT	HRV	Bad Tag List
TOP	PIA	Demand-Responsive Trip Confirmation
TOP	RTS	Demand-Responsive Trip Confirmation
PIA	TOP	Demand-Responsive Trip Request
RTS	TOP	Demand-Responsive Trip Request
TOP	FRV	Driver Instructions
TOP	DRV	Driver Instructions
TOP	RSV	Driver Instructions
HOP	HRV	Driver Instructions
LOP	LRV	Driver Instructions
RS	XFCH	Electronic Tolls
HOV	RS	Electronic Tolls
TOP	RTS	Emergency Acknowledge
EM	TOP	Emergency Acknowledge
TOP	RSV	Emergency Acknowledge
TOP	DRV	Emergency Acknowledge
LOP	LRV	Emergency Acknowledge
HOP	HRV	Emergency Acknowledge
TOP	PIA	Emergency Acknowledge
TOP	FRV	Emergency Acknowledge
EM	HOV	Emergency Acknowledge

Source entity	Destination entity	Data flow
PIA	TOP	Emergency Notification
TOP	EM	Emergency Notification
RTS	TOP	Emergency Notification
LRV	LOP	Emergency Notification and Vehicle Conditions
DRV	TOP	Emergency Notification and Vehicle Conditions
HRV	HOP	Emergency Notification and Vehicle Conditions
RSV	TOP	Emergency Notification and Vehicle Conditions
FRV	TOP	Emergency Notification and Vehicle Conditions
HOV	EM	Emergency Notification and Vehicle Conditions
EM	XLOC	Emergency Response Coordination
XLOC	EM	Emergency Response Coordination
LRV	XFCH	Fare and Payment Status
DRV	XFCH	Fare and Payment Status
RSV	XFCH	Fare and Payment Status
FRV	TOP	Fare and Payment Status
HOV	HOP	Fare and Payment Status
HOV	XFCH	Fare and Payment Status
HRV	HOP	Fare and Payment Status
HRV	XFCH	Fare and Payment Status
FRV	XFCH	Fare and Payment Status
RSV	TOP	Fare and Payment Status
LRV	LOP	Fare and Payment Status
DRV	TOP	Fare and Payment Status
TOP	ADM	Federal Reporting Data
ADM	XFCH	Federal Reporting Data
TOP	RTS	Flexible-Route Request Confirmation
TOP	PIA	Flexible-Route Request Confirmation
PIA	TOP	Flexible-Route Transit Request

Source entitv	Destination entitv	Data flow
RTS	TOP	Flexible-Route Transit Request
XMAP	HOP	GIS/Map Update
XMAP	TOP	GIS/Map Update
XMAP	LOP	GIS/Map Update
XMAP	ADM	GIS/Map Update
XMAP	ISP	GIS/Map Update
HOV	EM	Incident Reporting
RSV	PIA	On-board Information
HRV	PIA	On-board Information
FRV	PIA	On-board Information
LRV	PIA	On-board Information
HOV	PIA	On-board Information
DRV	PIA	On-board Information
TOP	RS	On-board Security Control
TOP	FRV	On-board Security Control
HOP	HRV	On-board Security Control
TOP	DRV	On-board Security Control
LOP	LRV	On-board Security Control
TOP	ADM	Operational Cost Data
LOP	ADM	Operational Cost Data
HOP	ADM	Operational Cost Data
RS	ISP	Parking Availability
RS	HRV	Parking Availability
RS	RSV	Parking Availability
RS	DRV	Parking Availability
RS	HOV	Parking Availability
RS	PIA	Parking Availability
RS	LRV	Parking Availability

Source entity	Destination entity	Data flow
RS	FRV	Parking Availability
RS	RTS	Parking Availability
ISP	RS	Parking Lot Data Request
XPAY	RTS	Payment
XPAY	LRV	Payment
XPAY	HOV	Payment
XPAY	FRV	Payment
XPAY	DRV	Payment
XPAY	RSV	Payment
XPAY	HRV	Payment
ISP	XFCH	Payment Requests
ADM	XFCH	Payment Requests
PIA	EM	Personal Security Alarm
RS	MNT	Physical Activities
RS	TOP	Physical Activities
ISP	FRV	Real Time Multimodal Information
ISP	LRV	Real Time Multimodal Information
ISP	DRV	Real Time Multimodal Information
ISP	HOV	Real Time Multimodal Information
ISP	HRV	Real Time Multimodal Information
ISP	RSV	Real Time Multimodal Information
MNT	TOP	Repair Requests
ISP	RS	Request for Toll Schedules
ISP	TM	Request for Traffic Information
RSV	RS	Request for Transit Signal Priority
TOP	TM	Request for Transit Signal Priority
DRV	RS	Request for Transit Signal Priority
LOP	TM	Request for Transit Signal Priority

Source entity	Destination entity	Data **flow**
LRV	RS	Request for Transit Signal Priority
FRV	RS	Request for Transit Signal Priority
MNT	MSV	Route Guidance
MSV	MNT	Route Guidance
ADM	LOP	Route Planning
ADM	TOP	Route Planning
RSV	TOP	Routing Information
FRV	TOP	Routing Information
DRV	TOP	Routing Information
HOP	RSV	Schedule and Fare Information
ADM	LOP	Schedule and Fare Information
ADM	ISP	Schedule and Fare Information
TOP	ISP	Schedule and Fare Information
HOP	HOV	Schedule and Fare Information
HOP	LRV	Schedule and Fare Information
HOP	HRV	Schedule and Fare Information
ADM	HOP	Schedule and Fare Information
TOP	FRV	Schedule and Fare Information
ADM	TOP	Schedule and Fare Information
LOP	ISP	Schedule and Fare Information
HOP	ISP	Schedule and Fare Information
LOP	LRV	Schedule and Fare Information
ADM	LOP	Schedule Generation
ADM	TOP	Schedule Generation
ADM	HOP	Schedule Generation
LOP	HOP	Service Coordination
HOP	LOP	Service Coordination
TOP	LOP	Service Coordination

Source entitv	Destination entitv	Data flow
TOP	HOP	Service Coordination
LOP	TOP	Service Coordination
HOP	TOP	Service Coordination
LOP	XTDC	Taxi Coordination
TOP	XTDC	Taxi Coordination
HOP	XTDC	Taxi Coordination
XTDC	TOP	Taxi Coordination
XTDC	HOP	Taxi Coordination
XTDC	LOP	Taxi Coordination
XFCH	RTS	Ticket Purchase
RTS	XFCH	Ticket Purchase Request
RS	ISP	Toll Schedules
TM	LOP	Traffic Information
TM	TOP	Traffic Information
TM	ISP	Traffic Information
HRV	XPAY	Transaction Status
XFCH	LOP	Transaction Status
FRV	XPAY	Transaction Status
XFCH	HOP	Transaction Status
RSV	XPAY	Transaction Status
HOV	XPAY	Transaction Status
LRV	XPAY	Transaction Status
DRV	XPAY	Transaction Status
XFCH	TOP	Transaction Status
RTS	XPAY	Transaction Status
XFCH	ADM	Transaction Status
XFCH	ISP	Transaction Status
ISP	LOP	Transit Information Request

Source entity	Destination entity	Data flow
ISP	TOP	Transit Information Request
ISP	HOP	Transit Information Request
RTS	ADM	Transit Passenger and Use Data
DRV	ADM	Transit Vehicle Passenger and Use Data
HRV	ADM	Transit Vehicle Passenger and Use Data
RSV	ADM	Transit Vehicle Passenger and Use Data
FRV	ADM	Transit Vehicle Passenger and Use Data
HOV	ADM	Transit Vehicle Passenger and Use Data
LRV	ADM	Transit Vehicle Passenger and Use Data
ISP	RSV	Traveler Information
TOP	HOV	Traveler Information
TOP	PIA	Traveler Information
TOP	FRV	Traveler Information
ISP	FRV	Traveler Information
ISP	RTS	Traveler Information
ISP	HOV	Traveler Information
ISP	LRV	Traveler Information
ISP	PIA	Traveler Information
HOP	HRV	Traveler Information
TOP	DRV	Traveler Information
ISP	HRV	Traveler Information
HOP	RTS	Traveler Information
TOP	RTS	Traveler Information
ISP	DRV	Traveler Information
TOP	RSV	Traveler Information
LOP	LRV	Traveler Information
LOP	RTS	Traveler Information
ISP	MSV	Traveler Information

Source entity	Destination entity	Data flow
MSV	TOP	Traveler Information Request
RTS	TOP	Traveler Information Request
FRV	TOP	Traveler Information Request
PIA	TOP	Traveler Information Request
DRV	TOP	Traveler Information Request
HRV	HOP	Traveler Information Request
MSV	HOP	Traveler Information Request
HOV	TOP	Traveler Information Request
RSV	TOP	Traveler Information Request
DRV	ISP	Traveler Information Request
RTS	ISP	Traveler Information Request
MSV	ISP	Traveler Information Request
PIA	ISP	Traveler Information Request
MSV	LOP	Traveler Information Request
HOV	ISP	Traveler Information Request
RTS	HOP	Traveler Information Request
HRV	ISP	Traveler Information Request
LRV	ISP	Traveler Information Request
RSV	ISP	Traveler Information Request
RTS	LOP	Traveler Information Request
LRV	LOP	Traveler Information Request
FRV	ISP	Traveler Information Request
PIA	LOP	Trip Confirmation
PIA	TOP	Trip Confirmation
RTS	LOP	Trip Confirmation
PIA	HOP	Trip Confirmation
RTS	HOP	Trip Confirmation
RTS	TOP	Trip Confirmation

Source entity	Destination entity	Data flow
HOV	TOP	Trip Reservation
FRV	TOP	Trip Reservation
LRV	LOP	Trip Reservation
HRV	HOP	Trip Reservation
PIA	TOP	Trip Reservation
RTS	TOP	Trip Reservation
DRV	TOP	Trip Reservation
RSV	TOP	Trip Reservation
TOP	PIA	Trip Reservation Confirmation
TOP	DRV	Trip Reservation Confirmation
TOP	HOV	Trip Reservation Confirmation
TOP	RSV	Trip Reservation Confirmation
TOP	RTS	Trip Reservation Confirmation
HOP	HRV	Trip Reservation Confirmation
TOP	FRV	Trip Reservation Confirmation
LOP	LRV	Trip Reservation Confirmation
FRV	TOP	Vehicle Location and Conditions
LRV	MNT	Vehicle Location and Conditions
RSV	MNT	Vehicle Location and Conditions
HRV	HOP	Vehicle Location and Conditions
RSV	TOP	Vehicle Location and Conditions
MSV	MNT	Vehicle Location and Conditions
LRV	LOP	Vehicle Location and Conditions
DRV	TOP	Vehicle Location and Conditions
MSV	TOP	Vehicle Location and Conditions
HRV	MNT	Vehicle Location and Conditions
DRV	MNT	Vehicle Location and Conditions
FRV	MNT	Vehicle Location and Conditions

Source entitv	Destination entitv	Data flow
HOV	TM	Vehicle Probe Data
DRV	TM	Vehicle Probe Data
FRV	TM	Vehicle Probe Data
RSV	TM	Vehicle Probe Data
HOP	XLOC	Violation Notification
TOP	XLOC	Violation Notification
LOP	XLOC	Violation Notification
ISP	DRV	Yellow Pages
ISP	FRV	Yellow Pages
ISP	LRV	Yellow Pages
ISP	HOV	Yellow Pages
ISP	HRV	Yellow Pages
ISP	RSV	Yellow Pages

Appendix B: APTS Vendor Questionnaire

Name: ______________________________ Title: _________________________ Date: ____________

Company: _____________________ Address: ____

Tel: ____________________ Fax: ___________________ Email: ______________________________

(Please feel **free** to attach a business card instead of **the** above information)

QUESTIONNAIRE

This questionnaire is being distributed by researchers at the University of California - Berkeley. Most generally, this research is examining the function of various information technologies that could be used by public transit agencies. Of equal importance is whether these technologies can be easily integrated with other existing or new information technologies. To this end, Part 1 of the survey asks some basic questions about your company, and Part 2 asks about specific products that your company offers to the transit industry. Your responses to this survey will be shared with transit agencies throughout the state of California as they plan and design their information systems and technologies.

Part 1 Background

First, we would like to have some general information regarding your company in general and its transit related products in particular.

1a. How many years has your company been in business? ____________ (number)

1b. How many years has your company been developing products specifically for the public transit industry? ____________ (number)

2a. How many full-time employees does your company have? ____________ (number)

2b. How many of your company's full-time employees work on products specifically for the transit industry? (Include all employees, such as line workers, engineers, managers, marketing and sales people, etc.) ____________ (number)

3. What percentage of your company's transit products are manufactured in the U.S.? ____________ (%)

4a. What is your company's total (gross) annual revenue? ____________ ($)

4b. What is your company's total (gross) annual revenue from products specifically for the transit industry? ____________ ($)

5. Would you be willing and available to participate in a fifteen-minute follow-up interview?

❑ Yes ❑ No

Part 2 Transit Products

In this part of the survey, we ask several questions about your products for the public transit industry. Please answer these to the best of your knowledge. The questions on pages **3** - *5* should be completed for each of your transit-related products. If your company has more than one transit product, *please copy and complete these pages **for** each additional product your company offers.* Also, please send any additional product literature with the questionnaire.

The survey asks for a short product description and how you would classify the product according to the following categories. In the appropriate space, use one of the following letters to indicate the product's category. If your product covers more than one category, please indicate all categories that apply.

Product Categories:

A = On-Vehicle - Products that are used inside transit vehicles (such as **GPS** receiver, fare box).

B = Operation Center - Products used in operation centers and dispatching (such as computer-aided dispatching, driver and vehicle logs).

C = Communications - Products used to provide communications between different units within the transit system (Such as mobile radio, cellular service).

D = Planning, Management and Administration - Hardware, software, and related products used for management, administration, planning and financing of a transit agency (such as Geographic Information Systems, Management Information Systems).

E = Roadside and In-Stop - Products utilized along the transit route, and inside bus stops and rail stations (such as information kiosk, signal priority devices, and passenger information signs).

F = Others - Please specify in product description

Product Description

1. Product: ____________________ 2. Category: __________

3. What does this product do? (Please give a short description): ____________________

____

____

____

____

4a. Is the product commercially available? ❑ Yes ❑ No

4b. If so, how long has the product been commercially available? ______(Years)/______(Months)

4c. When was the latest version or upgrade of this product released? __________ (Month/Year)

5. In offering this product, has your company worked cooperatively (i.e. through contributions of time and/or materials) with other companies and/or transit agencies to provide a complete system?

❑ Yes, Please list => Companies: ____________________

____

____

Transit Agencies: ____________________

____

____

❑ No

6. Has this product been field tested or placed into revenue service by any transit agencies to date?

❑ Yes, Please list => Example transit agencies: ____________________

____

____

❑ No

7. Is this product in conformance with any published industry standards (e.g. ISO, SAE, IEEE, etc.)?

❑ Yes, Please list => Applicable standards: ____________________

____

____

❑ No

Output Data Formats

In this section of the survey we are trying to discern whether data formats and transfer standards might be relevant or useful in the transit industry. Several of the questions below ask about output data formats, meaning the format in which data are available after the product has finished processing. The questions refers to such data formats as open orproprietary. For this survey, open dataformats are those formats that are described in technical documentation that is publicly or commercially available. Proprietary dataformats, on the other hand, are those not described in publicly or commercially available documentation.

8. Are the output data formats for this product open? (Check only one)

- Yes, all output data formats are open ❑ (Proceed to question 9)
- Some of the data formats are open and some proprietary ❑ (Proceed to question 9)
- No, all of the output data formats are proprietary ❑ (Proceed to question 11)

9. How were the open data formats for this product adopted? (Check all that apply)

- Our company created an open data format ❑
- Our company adopted an open data format that existed previously ❑
- Our company is a part of a team that created a standard ❑
- Our company is following a widely adopted industry standard ❑
  - => List any published standards: ______________________________

10. What benefits does your company expect from having open data formats for this product? (Check all that apply)

- The market is larger due to ability to interface with other company's products ❑
- Less chance that the product will become obsolete ❑
- Lower development costs related to the data formats ❑
- Other (Please specify)______________________________ ❑

11. What benefits does your company expect from having proprietary data formats for this product? (Check all that apply)

- Ability to control design ❑
- Cheaper to produce product ❑
- Better revenue potential ❑
- Product fits easily into a larger system our company produces ❑
- Better able to tailor product to individual customer's needs ❑
- Maintain product market share ❑
- Other (Please specify)______________________________ ❑
- Not Applicable ❑

12. Has your company received inquiries from transit agencies about developing products that have open output data formats or transfer protocols? (Check only one)

- Yes, we have received inquiries about producing open data formats for this product ❑
- No, we have not received inquiries about producing open data formats for this product ❑

13. To date, has your company participated materially (time or financial resources) to develop industry-wide data formats or transfer standards for this product? (Check only one)

- Yes, our company has participated materially ❑
  - => List any working or published standards: ______________________________
- No, our company has not participated materially ❑
- Our company is not aware of any such industry efforts to date ❑

14. Is your company interested in participating materially (time or financial resources) to develop industry-wide data formats or transfer standards for this product? (Check only one)

- Yes, we are interested ❑
- No, we are not interested ❑

Internal Data Formats

In this section of the survey we are interested in learning if your product's *internal dataformats* are open. ***Open*** *internal dataformats* mean that data passed between components have formats which are described in technical documentation that is publicly or commercially available. Otherwise, these data formats would be classified as *proprietary*. These questions are intended to discern whether a transit agency can mix-and-match components from several companies to create a similar product.

15. Are the *internal* data formats for this product open? (Check only one)
    - Yes, all internal data formats are open ❑ (Proceed to question 16)
    - Some of the internal data formats are open and some proprietary ❑ (Proceed to question 16)
    - No, all of the internal data formats are proprietary ❑ (Proceed to question 18)

16. How were the *internal* open data formats for this product adopted? (Check all that apply)
    - Our company created an open data format ❑
    - Our company adopted an open data format that existed previously ❑
    - Our company is a part of a team that created a standard ❑
    - Our company is following a widely adopted industry standard ❑
      => List any published standards: ____

17. What benefits does your company expect from having open data formats *within* this product? (Check all that apply)
    - Larger market due to consumer's ability to mix and match components ❑
    - Our company's flexibility to use other company's individual components ❑
    - Lower development costs related to data formats ❑
    - Other (Please specify)____ ❑

18. What benefits does your company expect from having proprietary data formats *within* this product? (Check all that apply)
    - Ability to control product design ❑
    - Cheaper to produce product ❑
    - Better revenue potential ❑
    - Better able to tailor product to individual customer's needs ❑
    - Maintain product market share ❑
    - Other (Please specify)____ ❑
    - Not applicable ❑

19. To date, has your company participated materially (time or financial resources) to develop industry-wide data formats or transfer standards *within* this product? (Check only one)
    - Yes, our company has participated materially ❑
      => List any working or published standards: _____________________________________
    - No, our company has not participated materially ❑
    - Our company is not aware of any such industry efforts to date ❑

20. Is your company interested in participating materially (time or financial resources) to develop industry-wide data formats *within* this product? (Check only one)
    - Yes, we are interested ❑
    - No, we are not interested ❑

Thank you for taking the time to complete this questionnaire!
Please include any additional product literature with your completed questionnaire.