CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Development of BRT Architecture: A System Engineering Approach

**Mark Hickman, Chin-Woo Tan,
Peter Lau, Wei-Bin Zhang**

California PATH Research Report
UCB-ITS-PRR-2006-11

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Report for Task Order 5603

June 2006

ISSN 1055-1425

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

Development of BRT Architecture: A System Engineering Approach

Mark Hickman[1]
Chin-Woo Tan[2]
Peter Lau
Wei-Bin Zhang

November 2005

Abstract

This report discusses the development of system architecture for Intelligent Transportation Systems (ITS) applications for Bus Rapid Transit (BRT) systems. In the course of the development of system architecture, it is critical to take a system engineering approach in the development of BRT architecture to assess BRT service needs (or features), the functional realization of these service needs and the means of technological implementation. Motivated by the National ITS architecture, the BRT architecture has a hierarchy of three layers: *application, physical,* and *logical*. The application layer consists of the BRT service needs or *features*. For the physical layer, we first discuss a functional analysis that begins with the identification of system operational features, followed by an identification of the functions that are needed to achieve these operational features. We create a physical architecture modeled around each of the BRT features. In the final step, the logical architecture is traced or mapped from the physical architecture in such a way that the physical layer will implement the processes identified in the logical architecture and assign them to subsystems, and the data flows that originate from one subsystem and end at another are grouped together into architecture flows.

Keywords: BRT architecture, hierarchical structure, BRT features

[1] March Hickman is an Associate Professor with the Department of Civil Engineering and Engineering Mechanics, University of Arizona. E-mail: mhickman@engr.arizona.edu.
[2] Chin-Woo Tan, Peter Lau, and Wei-Bin Zhang are with the California PATH Program at the University of California, Berkeley. E-mails: tan@eecs.berkeley.edu, p_lau@uclink.berkeley.edu, wbzhang@path.berkeley.edu.

Executive Summary

Transit agencies and implementers have been considering new and innovative approaches to address the increasingly costly issues of urban congestion and the associated pollution problems while providing efficient and effective surface transportation options. One innovative approach is the use of buses in lieu of light and/or heavy rail, in an integrated, well-defined system with design features similar to light rail rapid transit systems. Bus Rapid Transit (BRT) applies the concept of Intelligent Transportation Systems (ITS) and integrated land use and planning, to existing bus technologies in order to provide significantly faster operating speeds, greater service reliability, and increased rider convenience, matching the quality of rail transit when implemented in appropriate settings.

This report discusses the development of system architecture for BRT systems. A BRT system can be defined in terms of a set of operational features, and within each feature there are many data flows between different system components. In the course of the development of system architecture it is required to organize each layer of the system structure, define the communication between components, and maintain complexity at a manageable level. This architecture is a framework within which a BRT system is deployed. It includes requirements that dictate what functionality the architecture must satisfy. The architecture functionally defines the various components of the system and the information that is exchanged between them.

In order to develop an integrated application of ITS and other advanced technologies for BRT, it is critical to take a system engineering approach in the development of BRT architecture to assess BRT service needs (or features), the functional realization of these service needs and the means of technological implementation. We first discuss a functional analysis that begins with the identification of system operational features and characteristics translated from the application needs followed by an identification of the functions that are needed to achieve these operational features and characteristics. Once the functional decomposition is completed, the development of functional requirements will be initiated by associating the application needs with each of the system functions and translating these requirements into the subsystem-level requirements.

The National ITS architecture will be referenced in defining the BRT architecture in order to ensure compatibility. Motivated by the ITS architecture, the BRT architecture has a hierarchy of three layers: *logical, physical, application*. The application layer consists of the BRT service needs or *features*. We create a physical architecture modelled around each of the BRT features. The physical layer of BRT architecture will be developed to define BRT with a physical representation of how the system should provide the required functionality. In the final step, the logical architecture will be traced or mapped from the physical architecture in such a way that the physical layer will implement the processes identified in the logical architecture and assign them to subsystems, and the data flows that originate from one subsystem and end at another are grouped together into architecture flows. Interface requirements will also be defined.

1. Introduction

Transit agencies and implementers have been considering new and innovative approaches to address the increasingly costly issues of urban congestion and the associated pollution problems while providing efficient and effective surface transportation options. Constructing more roads is expensive and disruptive, and is not always an environmental sound approach. It is clear that the expansion of the road network alone is neither cost effective nor a sustainable solution to urban transportation issues. Public transportation in a cornerstone of modern urban planning, and it is in public interest to maximize the return on investment in public transportation, through the deployment of innovative technologies.

Light rail rapid transit system, of interest to many transit agencies, require a significant initial capital investment, and often suffer from high operating costs and operational inflexibility. In many instances, projects have become mired in opposition on grounds of cost and environmental impact at the planning stage. Light rail is not always an effective solution to the issue of urban public transportation. Transit buses, while providing an essential transportation service in many metropolitan areas, are generally slow and unreliable, and are viewed in a negative light by large sections of the public because of the above drawbacks.

One innovative approach is the use of buses in lieu of light and/or heavy rail, in an integrated, well-defined system with design features similar to light rail rapid transit systems. Bus Rapid Transit (BRT) applies the concept of Intelligent Transportation Systems (ITS) and integrated land use and planning, to existing bus technologies in order to provide significantly faster operating speeds, greater service reliability, and increased rider convenience, matching the quality of rail transit when implemented in appropriate settings. The transit industry nationwide has developed significant interest in BRT. Recent deployment of BRT systems have demonstrated that such systems can deliver similar levels of service as a rail corridor and offers significant advantages over the transitional rail system. For example, BRT has the flexibility of being able to be integrated with current urban settings and deployed progressively. Recent studies have shown that a BRT system achieving a service level comparable to rail will cost less than one-half of the rail system. BRT systems have proven to be a cost-effective alternative to rail-based public transportation. Ultimately the key contribution of BRT to the reduction of traffic congestion is the potential to attract non-traditional riders to public transportation, away from their private vehicles.

A BRT system is designed to address the sources of delay in traditional bus service. It is an incrementally enhanced transit mode, effectively providing a faster, more efficient and more passenger-friendly quality of service. This can be accomplished in multiple ways that include improvements to the infrastructure, vehicle road use, advanced stops/stations, quieter and cleaner vehicles, and integrating an amalgam of ITS technologies. These system deployments define and distinguish the characteristics of BRT as compared with traditional rail and transit systems. System characteristics and operational configurations of a BRT system are well-documented in ([1, 2]). Existing BRT systems have demonstrated most of the projected benefits for travelers. However, in addition to traveler benefits, there are benefits to vehicle operators and the transit agencies. The inclusion of advanced technology in the BRT system design is discussed at length in ([1, 2, 3]).

This objective of this research is to develop system architecture for BRT systems. A BRT system can be defined in terms of a set of operational features, and within each feature there are many data flows between different system components. In the course of the development of system architecture it is required to organize each layer of the system structure, define the communication between components, and maintain complexity at a manageable level. This architecture is a framework within which a BRT system is deployed. It includes requirements that dictate what functionality the architecture must satisfy. The architecture functionally defines what the pieces of the system are and the information that is exchanged between them. It defines "what must be done", not "how it will be done".

In order to develop an integrated application of ITS and other advanced technologies for BRT, it is critical to take a system engineering approach in the development of BRT architecture to assess BRT service needs (or features), the functional realization of these service needs and the means of technological implementation. The initial phase of the research involves a functional analysis that begins with the identification of system operational features and characteristics translated from the application needs followed by an identification of the functions that are needed to achieve these operational features and characteristics. Once the functional decomposition is completed, the development of functional requirements will be initiated by associating the application needs with each of the system functions and translating these requirements into the subsystem-level requirements.

Following the initial functional analysis, a functional architecture will be developed that incorporates all identified functions. The BRT architecture will organize, in the logical context, a full set of functions needed to implement the BRT features and the information flow among the functions. Similar to the National ITS architecture ([4]), processes and data flows are grouped to form BRT application functions and will be represented graphically by data flow diagrams, which decompose into several levels of detail.

The development of BRT architecture should serve two purposes: (1) to provide transit agencies with an interest in implementing BRT systems with a unified architecture framework that provides information about possible architectures for future BRT systems, (2) to provide the National ITS architecture team with guidance on enhancing the architecture for BRT, with the consideration of the BRT architecture as an extension to the National ITS architecture. As ITS technology is an important portion of a BRT system, the National ITS architecture will be referenced in defining the BRT architecture in order to ensure compatibility. Motivated by the ITS architecture, the BRT architecture has a hierarchy of three layers: *logical, physical, application*. The application layer consists of the BRT service needs or *features*. These features are, in essence, a set of characteristics that defines BRT and provides a distinctive signature that distinguishes a BRT system from ordinary bus transit. These features are developed as a summary of the characteristics of BRT introduced in ([1, 2]). To develop an architecture that is consistent with the structure of the National ITS Architecture, we create a physical architecture modeled around each of the BRT features. The physical layer of BRT architecture will be developed to define BRT with a physical representation of how the system should provide the required functionality. In the final step, the logical architecture will be traced or mapped from the physical architecture in such a way that the physical layer will implement the processes identified in the logical architecture and assign them to subsystems, and the data flows that originate from one subsystem and end at another are grouped together into architecture flows. Interface requirements will also be defined.

This report is organized as follows. In the next section, our development of BRT system architecture will begin with a careful study of the National ITS Architecture. Motivated by the structure of the ITS Architecture, the BRT architecture also has a hierarchy of three layers: *logical, physical, application.* The application layer will be first discussed. This layer consists essentially of ITS enhanced BRT services which we will label as "BRT features". The BRT features and their functional and communication requirements are then systematically identified and represented to construct a BRT physical architecture. A formal physical architecture for BRT is assembled by identifying existing Equipment Packages and Architecture Flows in the National ITS Architecture, and where necessary, generating new Equipment Packages to accommodate additional functions and new Architecture Flows to accommodate additional communication requirements in the BRT features. The BRT features are grouped into six categories and the physical architecture will be described for each of these categories. For each feature, Equipment Packages and Architecture Flows will be listed, and a feature diagram will be constructed. The feature diagrams are in the Appendix. In Section 4, a logical architecture is developed. Similar to the structure of the ITS logical layer, the BRT logical layer is constructed from Processes, Terminators and Data Flows. The logical architecture is detached from the physical implementation of the system, instead decomposing the functionality, or services of the system into processes, or process specifications.

2. Application Layer of BRT Architecture: ITS Enhanced BRT Features

A schematic diagram of the National ITS architecture hierarchy ([4]) is shown in Figure 2.1. Motivated by this architecture, the conceptual framework of BRT architecture has a hierarchy of three layers: *logical, physical, application.*

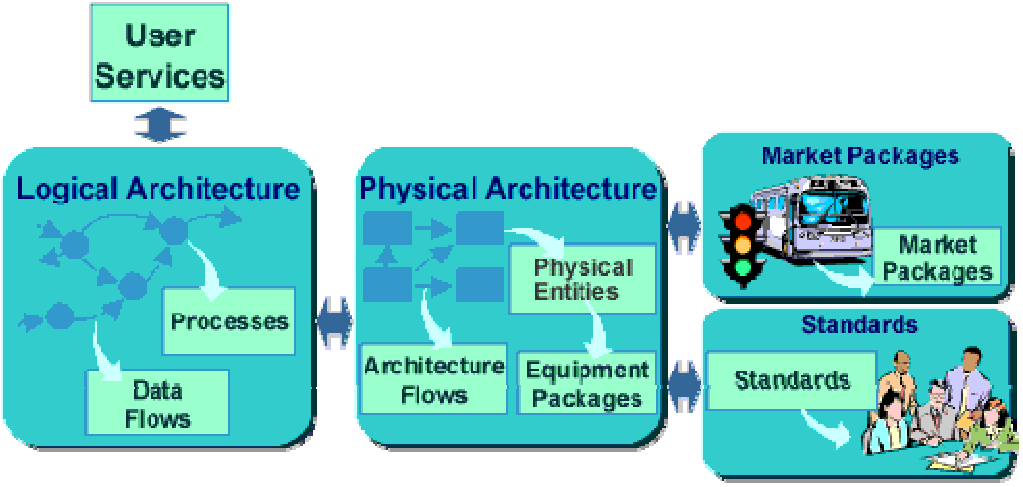


Figure 2.1: Hierarchical Structure of the National ITS Architecture

The *logical architecture* defines the processes (activities or functions) that are required to satisfy the BRT service needs. Many different processes must work together and share information to provide a BRT Service. Data flows identify the information that is shared by the processes. The *physical architecture* forms a high-level structure around the processes and data flows in the logical architecture. It defines the physical entities (*subsystems* and *terminators*) that make up a BRT system. It also defines the *architecture flows* that connect the various subsystems and terminators into an integrated system. The subsystems generally provide a rich set of capabilities, more than would be implemented at any one place or time. *Equipment packages* break up the subsystems into deployment-sized pieces.

The application layer in the National ITS architecture consists of *market packages* which represent slices of the physical architecture that address specific user services. As defined in [4], a market package collects together several different subsystems, equipment packages, terminators, and architecture flows that provide the desired service. By tracing the data flow links, one can traverse to the physical and logical architecture components that are associated with each market package. Similar to ITS architecture, the BRT *application layer* consists of BRT services which we will label as “BRT features”.

An Intelligent Transportation System (ITS) includes a variety of advanced technologies for collecting, processing and disseminating real-time data from vehicle and roadway sensors. The data are transmitted via a dedicated communications network and computer intelligence is used to transform these data into useful information for operating agencies, drivers and ultimately the customers. There are many ITS technologies and operational features that can be utilised for BRT systems. The various ITS applications that can be integrated into BRT systems are called “BRT features” and can be categorized into six areas as shown in Table 2.1. These features are taken from the “Characteristics of BRT Report” ([1]), the “ITS Enhanced BRT Report” ([2]), and the “TCRP-90 Report” ([3]). We have added fare collection, which is a separate area in [1], but left off “Advanced Communication Systems” as this is considered as a supporting technology, rather than a specific feature within BRT.

Feature Category	BRT Feature
(1) Vehicle Prioritization	(1.1) Signal Timing/Phasing (1.2) Station and Lane Access Control (1.3) Transit Signal Priority
(2) Driver Assist and Automation Technology	(2.1) Collision Warning (2.2) Collision Avoidance (2.3) Precision Docking (2.4) Vehicle Guidance (lane assist)
(3) Operations Management	(3.1) Automated Scheduling Dispatch System (including connection protection) (3.2) Vehicle Mechanical Monitoring and Maintenance (3.3) Vehicle Tracking (including buses as traffic probes) (3.4) Archived Data (3.5) Passenger Counting
(4) Fare Collection	(4.1) Station-based Electronic Fare Payment (4.2) Vehicle-based Electronic Fare Payment
(5) Passenger Information	(5.1) Traveler Information at Stations (5.2) Traveler Information in Vehicles (5.3) Traveler Information on Person (5.4) Pre-Trip Itinerary Planning
(6) Safety and Security	(6.1) Silent Alarm (6.2) Voice and Video Monitoring

Table 2.1: ITS Enhanced BRT features

In the next section, we will develop a physical (to some extent logical) architecture by mapping the existing market packages in the National ITS architecture to the BRT features. In some cases, there is a natural 1-to-1 mapping of existing architecture market packages to BRT features. In some other cases, the BRT features can be assembled from existing equipment packages in the national architecture; and, in a few cases, we may have to get into the details of process specifications (PSpecs) and data flows in the national architecture to define the BRT features.

3. Representation of BRT Features in the Physical Layer of BRT Architecture

In this section we discuss the development of a physical architecture for Intelligent Transportation System (ITS) elements within Bus Rapid Transit (BRT). In reaching this objective, we intend to make the greatest use of the existing National ITS Architecture where possible. At the same time, where the functional requirements of BRT systems make it necessary, we should identify necessary changes or additions to the National ITS Architecture. In the sub-sections below we outline a *systematic* process to obtain a physical architecture for BRT. Most broadly, the steps include:

1. Identification of BRT features and their functional and communication requirements;
2. A comparison of these BRT requirements with the National ITS Architecture (hereafter "NA"); and,
3. The development of a physical architecture for BRT using the structure of the ITS Architecture.

These steps are described in more detail below.

Throughout the research, a more systematic approach to representing the architecture for BRT was desired. We have adopted the concepts of "BRT Features" (roughly comparable to the "Market Packages" in the ITS architecture), "Equipment Packages", and "Architecture Flows" as an appropriate means of communicating the physical architecture for BRT ([4]). As described in previous work (e.g. [5]), these concepts improve the presentation and analysis of the physical architecture, as it may be implemented locally or regionally.

3.1 Development of the Physical Layer, Phase 1: Description of BRT Features

The initial phase of our research on the development of the BRT physical architecture involves the identification of BRT functional requirements. To do this, reference documents from the BRT literature, with broad national exposure, were reviewed. These included a report on BRT characteristics by Diaz *et al.* published in 2004 ([1]), a report on "ITS enhanced BRT" prepared by the Mitretek Systems in 2003 ([2]), and the "TCRP-90 Report" by Levinson *et al.* published in 2003 ([3]). The first two reports ([1, 2]) reports use a consistent representation of ITS features within Bus Rapid Transit; these we have labeled "BRT Features" and are listed in Table 2.1 in Section 2. Because of their fairly broad acceptance in the BRT community, these BRT features were chosen as the organizing concepts around which the BRT architecture would be formed.

None of these three reports ([1, 2, 3]) includes a formal systems *engineering description* of the functional requirements for BRT. As a result, a formal analysis of functional requirements was not possible. However, the descriptions of the BRT features in these three reports were compiled, and a composite description of the BRT feature was generated. This culminated in formal documentation of the BRT features, specifically a statement of the basic functions and communication needs for each feature. This analysis also led us to adopt the BRT features as the organizing concept for the BRT architecture.

3.2 Development of the Physical Layer, Phase 2: Comparison with National ITS Architecture

The second phase of the research involves a direct comparison of these BRT features with the Market Packages, and associated Equipment Packages and Architecture Flows, from the National Architecture (NA). This comparison was in keeping with the desired goal of using the NA as a reference for defining the BRT architecture.

Specifically, the description of the BRT feature, developed in the previous phase, is compared with the functional description of the NA Market Packages ([4]). In some cases, the BRT feature maps almost directly to a Market Package in the NA (e.g. Transit Vehicle Tracking). In other cases, the mapping is not nearly as obvious. In some cases, only certain functions of a Market Package are needed for a BRT feature (e.g. Passenger Counting in BRT vs. Transit Passenger Fare and Load Management in the NA), or some combination of Market Packages is needed (e.g., Collision Warning in BRT vs. Lateral Safety Warning, Longitudinal Safety Warning, and Intersection Safety Warning in the NA).

In comparing the BRT features to the NA Market Packages, the functions performed by each Equipment Package in the NA and the requisite Architecture Flows from the NA are examined. The comparison is conducted to determine: (a) whether the implied BRT functions are met in the existing Equipment Packages in the NA; and, (b) whether the necessary communication channels implied in the BRT literature are included in the Architecture Flows in the NA. Both commonalities and differences between the BRT features and the NA are identified.

3.3 Phase 3: Development of the Physical Architecture

In the third phase, a formal physical architecture for BRT is assembled. This involves:

- Identifying existing Equipment Packages and Architecture Flows in the NA that correspond to a given BRT feature;
- Where necessary, generating new Equipment Packages to accommodate additional functions in the BRT feature. This is done by identifying existing or new functions (Process Specifications, or P-specs) in the NA to accommodate the BRT feature. Specific P-specs for each new Equipment Package are identified.
- Where necessary, new Architecture Flows are generated to accommodate additional communications requirements in the BRT feature. This is done by identifying existing or new data flows in the NA to accommodate the BRT feature. Specific data flows for each new Architecture Flow are identified.

When these tasks are completed, the physical architecture is assembled, following the model of the presentation of the NA ([4]). The description of the physical architecture for BRT thus includes, for each BRT feature:

1. A functional description of the BRT feature, using language from the BRT reports and from the NA Market Packages;
2. A list of Equipment Packages, and in some cases, additional P-specs, for the BRT feature;
3. A list of Architecture Flows, and in some cases, additional data flows, for the BRT feature; and,
4. A diagram of the physical architecture for the BRT feature, including the relevant Equipment Packages and Architecture Flows, and also based on the subsystems and terminators from the NA.

In the subsections that follow, we will describe the physical architecture for BRT for each of the BRT features. For each feature, Equipment Packages and Architecture Flows will be listed, and a feature diagram will be constructed, exactly like what we have outlined above. For the ease of presentation, the feature diagrams are in the Appendix. We recall that the BRT features are grouped into six categories, so the physical architecture will be described for each of these categories, in the order as they appear in Table 2.1.

3.4 Physical Architecture for Feature Category (1) "Vehicle Prioritization"

This technology group includes methods to provide preference or priority to the BRT vehicles. Signal timing or phasing and signal priority help BRT vehicles minimize delay caused by having to stop for traffic at intersections. Assess control provides the BRT vehicles with unencumbered entrance to and exit from their facilities. All prioritization schemes for BRT vehicles reduce travel delay and increase reliability of the BRT operation.

(1.1) Signal Timing / Phasing

Description of feature

This feature establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Coordination between traffic and transit management is intended to improve on-time performance of the transit system to the extent that this can be accommodated without degrading overall performance of the traffic network. The feature provides optimization of traffic signals along a corridor to make better use of available green time capacity by favoring peak, e.g., BRT flows ([1, p. 2-51], {2, p.15}).

Relation to National ITS market package(s): APTS78

It appears that the primary issue here is that the traffic management system, in the form of signal control, considers the BRT service in determining traffic signal timing. The most relevant market package is APTS7 Multi-modal Coordination.

Market Package APTS7 – Multi-modal Coordination

This market package establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Multimodal coordination between transit agencies can increase traveler convenience at transit transfer points and clusters (a collection of stops, stations, or terminals where transfers can be made conveniently) and also improve operating efficiency. Transit transfer information is shared between Multimodal Transportation Service Providers, Transit Agencies, and ISPs. Coordination between traffic and transit management is intended to improve on-time performance of the transit system to the extent that this can be accommodated without degrading overall performance of the traffic network. More limited local coordination between the transit vehicle and the individual intersection for signal priority is also supported by this package.

Equipment packages that are relevant for simple static transit priority in considering signal timing are:

- TMC Signal Control (in the Traffic Management subsystem)
- TMC Multimodal Coordination (in the Traffic Management subsystem)
- Transit Center Multimodal Coordination (in the Transit Management subsystem)

These equipment packages provide for communication between the Traffic and Transit Management subsystems.

Notes on architecture representation

The architecture flows here should include those from APTS7, but leaving out explicit dynamic allocation of priority (see separate BRT feature below). The coordination with other transit agencies included in APTS7 should instead be included with the BRT feature of the Automated Scheduling Dispatch System (see separate BRT feature previously). The result is that many of the subsystems and terminators in APTS7 can be removed, and some of the architecture flows relating directly to dynamic priority can be deleted.

Recommendations on architecture representation

Several adjustments to APTS7 must be made for this BRT feature:

The following subsystems and terminators can be removed (with their associated architecture flows): Multimodal Transportation Service Provider, Other Transit Management, and Parking Management. Other subsystems, terminators, and architecture flows associated with dynamic signal priority can also be removed, associated with the Transit Vehicle and Roadway subsystems. The specific architecture flows include (among others) "traffic control priority request" and "traffic control priority status" between Traffic Management and Transit Management. This greatly simplifies the architecture representation from APTS7.

Equipment Packages

Equipment Package	Subsystem
TMC Multimodal Coordination	Traffic Management
TMC Signal Control	Traffic Management
Transit Center Multimodal Coordination	Transit Management

Architecture Flows

From	To	Architecture Flow
Traffic Management	Transit Management	request transit information
Transit Management	Traffic Management	transit system data

(1.2) Station and Lane Access Control

Description of feature

This feature allows access to dedicated BRT running ways and stations with variable message signs and gate control systems. The feature requires the installation of barrier control systems that identify a driver and vehicle and/or similar surveillance and monitoring systems. Remote control systems allow the gates to be controlled from a central location or from a vehicle at the gate/barrier location (e.g. utilizing an electronic transponder to allow access while the BRT vehicle is operating at highway speeds). Surveillance systems allow operating personnel to visually verify the safe activation of the gate system and driver information systems (e.g., DMS) provide information to bus operators and motorists in the vicinity of the system. The equipment managed by this market package includes the control and monitoring systems, the field devices (e.g., gates, warning lights, DMS, CCTV cameras) at the location(s), and the information systems that notify other systems of the system status ([1, p.2-51], [2, p.15]).

Relation to National ITS market package(s): ATMS21

There is no market package that is directly relevant to this BRT feature. The apparently closest market package is ATMS21 Roadway Closure Management.
Market Package ATMS21 –Roadway Closure Management

This market package closes roadways to vehicular traffic when driving conditions are unsafe, maintenance must be performed, and other scenarios where access to the roadway must be prohibited. The market package includes automatic or remotely controlled gates or barriers that control access to roadway segments including ramps and traffic lanes. Remote control systems allow the gates to be controlled from a central location or from a vehicle at the gate/barrier location, improving system efficiency and reducing personnel exposure to unsafe conditions during severe weather and other situations where roads must be closed. Surveillance systems allow operating personnel to visually verify the safe activation of the closure system and driver information systems (e.g., DMS) provide closure information to motorists in the vicinity of the closure. The equipment managed by this market package includes the control and monitoring systems, the field devices (e.g., gates, warning lights, DMS, CCTV cameras) at the closure location(s), and the information systems that notify other systems of a closure. This market package covers general road closure applications; specific closure systems that are used at railroad grade crossings, drawbridges, reversible lanes, etc. are covered by other ATMS market packages.

Notes on architecture representation

Several architectures are possible for lane and station access control:

- Vehicle – infrastructure (like electronic tolls)
- Vehicle – center, with center-based control of access
- Infrastructure-based vehicle sensors (loops, video, etc.)

ATMS21 seems to include each of these options, with the possible exception of direct communication between the vehicle and the management center. In this case, there should be some communication of the BRT vehicle request for access to the barrier management (e.g. in the traffic management subsystem), without going directly through roadside devices.

Another concern in adapting ATMS21 is the actual center granting access to lanes and stations. In some cases, this might be the Traffic Management subsystem, if the traffic agency has jurisdiction on the roadway facilities. It could also naturally fall on the Transit Management subsystem. The language of “dedicated BRT running ways” in the CBRT suggests that the transit management subsystem would have jurisdiction, but this may not always be the case.

The most probable course of action is to leave the access control function in the traffic management subsystem, but to assume that the physical entity of the transit management center might subsume this traffic management subsystem in the case of BRT facility access.

Recommendations on architecture representation

One may begin with an architecture that is similar to ATMS21. The following changes to this architecture are necessary. The transit vehicle subsystem should be included. An equipment package for the transit vehicle (e.g., “Transit Vehicle Barrier System Control”) should be created, modeled after existing equipment packages for maintenance and construction vehicles and emergency vehicles.

Architecture flows between the transit vehicle and the roadway would include existing flows regarding barrier control. New flows between the transit vehicle and the traffic management subsystem should be added, to include a request for gate access (“barrier system control request”) and a response (“barrier system status”). This allows for direct communication between the vehicle and the traffic management subsystem for access control.

Roadway equipment packages would be similar, with the exception of Roadway Work Zone Traffic Control, which is not necessary. The traffic management subsystem from ATMS21, with the associated equipment packages (Collect Traffic Surveillance, Barrier System Management, and TMC Traffic Information) will be maintained as the Traffic Management subsystem. This could be included in a transit management center as one architecture option.

An interface between traffic management and transit management could be included as is currently in ATMS21: a road network information architecture flow (not shown in the Architecture graphic). However, there is no need for an explicit equipment package in the transit management subsystem.

Equipment Packages

Equipment Package	Subsystem
Field Barrier System Control	Roadway
Roadway Basic Surveillance	Roadway
Roadway Equipment Coordination	Roadway
Roadway Traffic Information Dissemination	Roadway
Barrier System Management	Traffic Management
Collect Traffic Surveillance	Traffic Management
Transit Vehicle Barrier System Control	Transit Vehicle

The “Transit Vehicle Barrier System Control” is a new equipment package consisting of the on-board systems necessary to activate the barrier system and/or to request access. Since the Transit Vehicle is not explicitly included in the National Architecture for this market package, P-specs in this new equipment package need to be developed. However, these would be essentially similar to the P-specs for the “On-Board EV Barrier System Control” equipment package for the Emergency Vehicle subsystem:

- 5.3.5-Provide Emergency Personnel Interface (excluding the emergency management and response functions)
- 5.3.9-Control Barrier Systems from Emergency Vehicle

Architecture Flows

From	To	Architecture Flow
Roadway	Driver	driver information
Roadway	Traffic Management	barrier system status
Roadway	Traffic Management	roadway information system status
Roadway	Traffic Management	traffic images
Roadway	Transit Vehicle	barrier system status
Traffic Management	Roadway	barrier system control
Traffic Management	Roadway	roadway information system data
Traffic Management	Roadway	video surveillance control
Traffic Management	Transit Management	road network conditions
Traffic Management	Transit Vehicle	barrier system status
Transit Vehicle	Roadway	barrier system control
Transit Vehicle	Traffic Management	barrier system activation request

The architecture flow “barrier system activation request” is a new architecture flow, containing the request from the Transit Vehicle to be given access. This consists of a single data flow, m8odeled after the “barrier system activation request from emerg” data flow in the architecture. Essentially, the new architecture flow “barrier system activation request” should include only one data flow, “barrier system activation request from transit”, and this new data flow should be identical (in the sub-data flows) to the existing data flow “barrier system activation request from emerg”.

(1.3) Transit Signal Priority

Description of feature

This feature establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Coordination between traffic and transit management is intended to improve on-time performance (schedule adherence, reliability, and speed) of the transit system, to the extent that this can be accommodated without degrading overall performance of the traffic network. More limited local coordination between the transit vehicle and the individual intersection for signal priority is also supported by this feature.

This feature requires traffic signal controllers and software and TSP capable equipment on the transit vehicle and at the intersection for identifying the transit vehicle and adjusting the signal timing or generating a low priority request when appropriate. Architecture options include (i) direct communication between the BRT vehicle and the local signal; (ii) BRT vehicle detection is communicated to the Traffic Management Subsystem; or (iii) BRT vehicle detection is communicated to the Transit Management Subsystem, and a priority request is then submitted to the Traffic Management Subsystem. In cases (ii) and (iii), the Traffic Management Subsystem then either grants or denies priority to the local signal controller ([1, p. 2-52], [2, p. 15], [3, p.7-7 to 7-9]).

Relation to National ITS market package(s): APTS7

Supplementing the basic signal control, this feature explicitly provides for signal priority.
Market Package APTS7 - Multi-modal Coordination

This market package establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Multimodal coordination between transit agencies can increase traveler convenience at transit transfer points and clusters (a collection of stops, stations, or terminals where transfers can be made conveniently) and also improve operating efficiency. Transit transfer information is shared between Multimodal Transportation Service Providers, Transit Agencies, and ISPs. Coordination between traffic and transit management is intended to improve on-time performance of the transit system to the extent that this can be accommodated without degrading overall performance of the traffic network. More limited local coordination between the transit vehicle and the individual intersection for signal priority is also supported by this package.

Notes on architecture representation

Several architectures are possible:

- Vehicle – controller
- Vehicle – traffic control center – controller
- Vehicle – transit control center – traffic control center – controller

Adaptive control requires knowledge of vehicle schedule adherence, which can be kept on board the vehicle or transmitted from the transit control center Each of the three alternative architectures is included in APTS7.

The architecture flows here should include those from APTS7. The coordination with other transit agencies included in APTS7 should instead be included with the BRT feature of the Automated Scheduling Dispatch System (see separate BRT feature previously).

Recommendations on architecture representation

A few small adjustments to APTS7 must be made for this BRT feature. The following subsystems and terminators can be removed (with their associated architecture flows): Multimodal Transportation Service Provider, Other Transit Management, and Parking Management. All other architecture flows, subsystems and terminators can be retained.

Equipment Packages

Equipment Package	Subsystem
Roadway Signal Priority	Roadway
TMC Multimodal Coordination	Traffic Management
TMC Signal Control	Traffic Management
Transit Center Multimodal Coordination	Transit Management
On-board Transit Signal Priority	Transit Vehicle

Architecture Flows

From	To	Architecture Flow
Roadway	Traffic Management	request for right-of-way
Roadway	Traffic Management	signal control status
Traffic Management	Roadway	signal control data
Traffic Management	Transit Management	request transit information
Traffic Management	Transit Management	traffic control priority status
Transit Management	Traffic Management	traffic control priority request
Transit Management	Traffic Management	transit system data
Transit Management	Transit Vehicle	transit schedule information
Transit Vehicle	Roadway	local signal priority request
Transit Vehicle	Transit Management	transit vehicle schedule performance

3.5 Physical Architecture for Feature Category (2) "Driver Assist and Automation Technology"

This technology group includes Intelligent Vehicle Initiatives (IVI) which provide automated controls for a BRT vehicle. Use of collision warning function assists a driver to operate a BRT vehicle safely. Use of collision avoidance, lane assist, and precision docking functions provide for direct control of the BRT vehicle when making avoidance, guidance or docking maneuvers. All IVI functions help reduce frequency and severity of crashes and collisions and provide reduced travel and boarding times.

(2.1) Collision Warning

Description of feature

This feature allows for longitudinal warning. It utilises safety sensors and collision sensors. It requires on-board sensors to monitor the areas in front of and behind the vehicle and present warnings to the driver about potential hazards such as roadside obstructions, other vehicles, pedestrians, infrastructure elements or any other element which is in a potential path of the vehicle. In addition, this feature also allows for lateral warning. It requires on-board sensors to monitor the areas to the sides of the vehicle and present warnings to the driver about potential hazards as described above.

This feature will determine the probability of a collision in an equipped intersection (either highway-highway or highway-rail) and provide timely warnings to drivers in response to hazardous conditions. Monitors in the roadway infrastructure assess vehicle locations and speeds near an intersection. Using this information, a warning is determined and communicated to the approaching vehicle using a short range communications system. Information can be provided to the driver ([2, p.15], [2, p.7-16]).

Relation to National ITS market package(s): AVSS03, AVSS04, AVSS05

Market Package AVSS03 - Longitudinal Safety Warning

This market package allows for longitudinal warning. It utilises safety sensors and collision sensors. It requires on-board sensors to monitor the areas in front of and behind the vehicle and present warnings to the driver about potential hazards.

Market Package AVSS04 - Latitudinal Safety Warning

This market package allows for lateral warning. It utilises safety sensors and collision sensors. It requires on-board sensors to monitor the areas to the sides of the vehicle and present warnings to the driver about potential hazards.

Market Package AVSS05 - Intersection Safety Warning

This market package will determine the probability of a collision in an equipped intersection (either highway-highway or highway-rail) and provide timely warnings to drivers in response to hazardous conditions. Monitors in the roadway infrastructure assess vehicle locations and speeds near an intersection. Using this information, a warning is determined and communicated to the approaching vehicle using a short range communications system. Information can be provided to the driver through the market package ATIS9--In-Vehicle Signing.

Headway information is contained in the dataflow fbv_vehicle_headway, and also duplicated in fbv_vehicle_proximity_data. The latter is a comprehensive dataflow address both the longitudinal and lateral status of the vehicle. It is not clear why the same information is conveyed to the warning and vehicle control systems in incompatible data structures.

Notes on architecture representation

It is not clear whether AVSS03 and AVSS04 act on the proximity of pedestrians. In a BRT environment, the presence of riders on the running way near station stops and along the prescribed route is a important hazard.

Warning can be given issued to following drivers if the rear headway is violated. However this will require the creation of a new architecture flow between the current vehicle and other vehicles, and the creation of associated data flows and processes.

Recommendations on architecture representation

AVSS03, AVSS04 and AVSS05 form a reasonable basis for Collision Warning from a BRT perspective. AVSS03 and AVSS04 should include incorporate the dataflow From_Potential_Obstacles, which includes the presence pedestrians in its description.

AVSS03 should be extended to include a data flow between the BRT vehicle and following vehicle(s) so that extra-vehicular warnings can be issued when the rear following distance is violated.

Minimal Action: This feature can be satisfied by a union of AVSS03, AVSS04 and AVSS05.
Equipment Packages

Equipment Package	**Subsystem**
Vehicle Longitudinal Warning System	Vehicle
Vehicle Lateral Warning System	Vehicle
Roadway Intersection Collision Warning	Roadway Subsystem
Vehicle Intersection Collision Warning	Vehicle

Architecture Flows

Source	**Architecture Flow**	**Destination**
Basic Vehicle	basic vehicle measures	Vehicle
Driver	driver inputs	Vehicle
Roadway Environment	roadway characteristics	Vehicle
Vehicle	driver updates	Driver
Roadway Subsystem	intersection status	Vehicle
Potential Obstacles	physical presence	Vehicle

(2.2) Collision Avoidance

<u>Description of feature</u>

This feature automates the speed and headway control functions on board the vehicle. It utilises safety sensors and collision sensors combined with vehicle dynamics processing to control the throttle and brakes. It requires on-board sensors to measure longitudinal gaps and a processor for controlling the vehicle speed.

This feature also automates the steering control on board the vehicle. It utilises safety sensors and collision sensors combined with vehicle dynamics processing to control the steering. It requires on-board sensors to measure lane position and lateral deviations and a processor for controlling the vehicle steering.

This feature will determine the probability of an intersection collision. This feature builds on the Intersection Collision Warning infrastructure and in-vehicle equipment and adds equipment in the vehicle that can take control of the vehicle in emergency situations. The same monitors in the roadway infrastructure are needed to assess vehicle locations and speeds near an intersection. This information is determined and communicated to the approaching vehicle using a short range communications system. The vehicle uses this information to develop control actions which alter the vehicle's speed and steering control and potentially activate its pre-crash safety system ([2, p.15], [3, p. 7-16]).

<u>Relation to National ITS market package(s)</u>: AVSS08, AVSS09, AVSS10

Market Package AVSS08 - Advanced Vehicle Longitudinal Control

This market package automates the speed and headway control functions on board the vehicle. It utilises safety sensors and collision sensors combined with vehicle dynamics processing to control the throttle and brakes. It requires on-board sensors to measure longitudinal gaps and a processor for controlling the vehicle speed.

Market Package AVSS09 - Advanced Vehicle Lateral Control

This market package automates the steering control on board the vehicle. It utilises safety sensors and collision sensors combined with vehicle dynamics processing to control the steering. It requires on-board sensors to measure lane position and lateral deviations and a processor for controlling the vehicle steering.

Market Package AVSS10 - Intersection Collision Avoidance

This market package will determine the probability of an intersection collision and provide timely warnings to approaching vehicles so that avoidance actions can be taken. This market package builds on the Intersection Collision Warning infrastructure and in-vehicle equipment and adds equipment in the vehicle that can take control of the vehicle in emergency situations. The same monitors in the roadway infrastructure are needed to assess vehicle locations and speeds near an intersection. This information is determined and communicated to the approaching vehicle using a short range communications system. The vehicle uses this information to develop control actions which alter the vehicle's speed and steering control and potentially activate its pre-crash safety system.

There is no BRT requirement to issue warning to approaching vehicles. Reference to this capability in AVSS10 can be removed.

Notes on architecture representation

A simple union of AVSS08, AVSS09 and AVSS10 can satisfy this BRT feature.
Equipment Packages

Equipment Package	Subsystem
Vehicle Longitudinal Control	Vehicle
Vehicle Lateral Control	Vehicle
Roadway Intersection Collision Warning	Roadway Subsystem
Vehicle Intersection Control	Vehicle

Architecture Flows

Source	Architecture Flow	Destination
Basic Vehicle	basic vehicle measures	Vehicle
Driver	driver inputs	Vehicle
Potential Obstacles	physical presence	Vehicle
Roadway Environment	roadway characteristics	Vehicle
Vehicle	vehicle control	Basic Vehicle
Vehicle	driver updates	Driver
Roadway Subsystem	intersection status	Vehicle

(2.3) Precision Docking

Description of feature

This feature automates the positioning of a BRT vehicle precisely relative to the curb or loading platform. The driver can maneuver the bus into the loading area and then turn it over to automation. Sensors continually determine the lateral distance to the curb, front, and rear, and the longitudinal distance to the end of the bus loading area ([1, p. 3-5, p. 3-74], [2, p. 16], [3, p. 7-14]).

Relation to National ITS market package(s): None

The concept of precision docking is not addressed by existing ITS Market Packages. Much of the capabilities required to implement Precision Docking is included in the processes already present to address Vehicle Lateral Control. Although Precision Docking may be subsumed by, or treated as a subset of the Vehicle Lateral Control equipment package, there exist major differences, in intent (safety vs. operational efficiency) and design (high-speed vs. low-speed and high precision). The more logical choice would be to create a new, dedicated Equipment Package.

Notes on architecture representation

Create a new Equipment Package for Transit Precision Docking, using as many of the existing *Lateral Vehicle Control* PSpecs and dataflows as possible. (For example, 3.2.3.4.5-Provide Vehicle Control Data Interface.) The description of this Equipment Package should also mention lane access control within a transit station, where the bus is guided to an assigned docking platform where multiple platforms are present and positioned side by side.

Minimal Action: Create a new Equipment Package for *Transit Precision Docking* building upon the components of the *Lateral Vehicle Control* Equipment Package. Create a new Market Package to utilise the newly created *Transit Precision Docking* Equipment Package.

Equipment Packages

Equipment Package	**Subsystem**
Precision Docking	Vehicle

Precision Docking is a new equipment package. The description for this equipment package is given below:

Precision Docking

This equipment package shall provide the capability for positioning a BRT vehicle precisely relative to the curb or loading platform, through automated longitudinal control and lateral steering. It requires onboard sensors to measure the lateral and longitudinal deviation, dedicated roadside markers to indicate the approach path and desired stopping position, and a processor to control speed and steering.

From an architectural perspective the *Precision Docking* equipment package is the union of *Lateral Vehicle Control* and *Longitudinal Vehicle Control*.

This equipment package contains the following Pspecs:

- 3.1.3-Process Vehicle On-board Data
- 3.2.1-Provide Driver Interface
- 3.2.3.1-Provice Command Interface
- 3.2.3.3-Process data for Vehicle Actuators
- 3.2.3.4.1-Provide Speed Servo Control

3.2.3.4.2-Provide Headway Servo Control
3.2.3.4.3-Provide Lane Servo Control
3.2.3.4.4-Provide Change Lane Servo Control
3.2.3.4.5-Provide Vehicle Control Data Interface
6.2.5-Provide Driver Information Interface

Precision Docking differs from collision avoidance or lane assist in that it is a slow speed, high precision system. Special markers mark the approach to the platform and provide the precision and reliability required. These markers are part of the Roadway Environment. The geometric information conveyed by these markers is part of the *roadway characteristics* dataflow.

Architecture Flows

Source	Architecture Flow	Destination
Basic Vehicle	basic vehicle measures	Vehicle
Driver	driver inputs	Vehicle
Potential Obstacles	physical presence	Vehicle
Roadway Environment	roadway characteristics	Vehicle
Vehicle	vehicle control	Basic Vehicle
Vehicle	driver updates	Driver
Roadway Subsystem	intersection status	Vehicle

(2.4) Vehicle Guidance (Lane Assist)

Description of feature

This feature enables "hands-off" operation of the BRT vehicle on the automated portion of the right of way. Implementation requires lateral lane holding, vehicle speed and steering control, and right of way check-in and checkout, using sensors on the roadway and the BRT vehicle. Lane Assist can allow the BRT vehicle to travel at higher speeds than otherwise would be possible due to the physical constraints of the right of way ([1, p. 2-54, p. 3-5], [2, p.15], [3, p. 7-14]).

Relation to National ITS market package(s): AVSS11

This function is part of the Automatic Highway System (AHS) Market Package, AVSS11. On an AHS roadway, the capabilities of AVSS11 are more than sufficient to satisfy the BRT Lane Assist requirements. However AVSS11 is narrowly defined in terms AHS. No current provisions exist for Lane Assist on running ways without AHS infrastructure, or with non-AHS compliant infrastructure.

AVSS11 - Automatic Highway System

This market package enables “hands-off” operation of the vehicle on the automated portion of the highway system. Implementation requires lateral lane holding, vehicle speed and steering control, and Automated Highway System check-in and checkout. This market package currently supports a balance in intelligence allocation between infrastructure and the vehicle pending selection of a single operational concept by the AHS consortium.

<u>Notes on architecture representation</u>

AVSS11 can form the basis of a Lane Assist Market Package. Specific references to AHS are removed. BRT lane assist does not require a full blown implementation of AHS. For example, the system only needs to cater to a specific set of BRT transit vehicles, as opposed to all road users.

<u>Minimal Action:</u> Use AVSS11 as a basis. Create duplicate Equipment Packages, namely of, *Roadway Systems for AHS, TMC for AHS and Vehicle Systems for AHS*, and remove specific references to AHS.

The *TMC for AHS* Equipment Package can be moved to the *Transit Management* subsystem, and renamed *Transit Center Lane Assist*, whilst preserving its current function.

<u>Equipment Packages</u>

Equipment Package	**Subsystem**
Roadway Systems for Lane Assist	Roadway Subsystem
Transit Center for Lane Assist	Transit Management
Vehicle Systems for Lane Assist	Vehicle

Unlike a fully developed AHS system there is no need for Lane Assist to cater to the arbitrary arrival and departure of unannounced vehicles to and from the system. Lane Assist is to be deployed on a dedicated right-of-way closed to all but qualified BRT vehicles.

These three equipment packages are adapted from their AHS equivalents in the National ITS architecture. References to AHS in the involved Pspecs have been removed and replaced with references to *lane assist*.

The renamed Pspecs and their containing equipment packages are listed below:

Roadway Systems for Lane Assist (formerly *Roadway Systems for AHS*)
- 3.2.5-Check Vehicle for Lane Assist eligibility
- 3.2.6-Manage Lane Assist Check-in and Check-out
- 3.2.8-Provide Automated Lane Changing

Transit Center for Lane Assist (formerly *TMC for AHS*)
- 3.2.7-Manage Lane Assist Operations

Note: reflecting a de-emphasis away from traffic management, *Transit Center for Lane Assist* has be relocated from *Traffic Management* to the *Transit Management* subsystem.

Vehicle Systems for Lane Assist (formerly *Vehicle Systems for AHS*)

3.1.3-Process Vehicle On-board Data
3.2.1-Provide Driver Interface
3.2.2-Provide Lane Assist Control
3.3.4.3-Manage Platoon Following
3.2.3.3-Process data for Vehicle Actuators
3.2.3.6-Communicate with other Platoon Vehicles
3.2.4-Process Sensor Data for Lane Assist input
6.2.5-Provide Driver Information Interface

Architecture Flows

Source	Architecture Flow	Destination
Basic Vehicle	basic vehicle measures	Vehicle
Driver	driver inputs	Vehicle
Other Vehicle	vehicle to vehicle coordination	Vehicle
Potential Obstacles	physical presence	Vehicle
Roadway Environment	roadway characteristics	Vehicle
Roadway Subsystem	lane assist status	Transit Management
Roadway Subsystem	lane assist control data	Vehicle
Transit Management	lane assist control information	Roadway Subsystem
Vehicle	vehicle control	Basic Vehicle
Vehicle	driver updates	Driver
Vehicle	vehicle to vehicle coordination	Other Vehicle
Vehicle	lane assist vehicle data	Roadway Subsystem

3.6 Physical Architecture for Feature Category (3) "Operations Management"

This technology group includes automation methods which provide enhanced operations management for a BRT fleet. An advanced communication system can be used as a backbone to support various functions of fleet operational management. Use of automated scheduling dispatch system and a vehicle tracking method assists BRT management to best utilise the BRT vehicles. Use of vehicle mechanical monitoring and maintenance assists in minimizing downtime of the BRT vehicles. All operations management functions improve efficiencies that support a reliable service and reduced travel times.

(3.1) Automated Scheduling Dispatch System (with Connection Protection)

Description of feature

This feature utilises real-time vehicle data (location, schedule adherence, passenger counters) to manage all BRT vehicles in the system and insure proper level of service for passengers. The feature requires a communication system and vehicle tracking components integrated with an ASDS software package ([1], p.2-55), ([2], p.17).

This feature performs vehicle routing and scheduling, as well as automatic operator assignment and system monitoring for fixed-route and flexible-route transit services. This service determines current schedule performance using AVL data and provides information displays at the Transit Management Subsystem. Static and real time transit data is exchanged with Information Service Providers, and with Traffic Management and Maintenance and Construction Management.

This feature also establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Multimodal coordination between transit agencies can increase traveler convenience at transit transfer points and clusters (a collection of stops, stations, or terminals where transfers can be made conveniently) and also improve operating efficiency. Transit transfer information is shared between Multimodal Transportation Service Providers, Transit Agencies, and ISPs.

Relation to National ITS market package(s): APTS2, APTS7

Market package APTS2 – Transit Center Fixed-Route Operations

This market package performs vehicle routing and scheduling, as well as automatic operator assignment and system monitoring for fixed-route and flexible-route transit services. This service determines current schedule performance using AVL data and provides information displays at the Transit Management Subsystem. Static and real time transit data is exchanged with Information Service Providers where it is integrated with that from other transportation modes (e.g., rail, ferry, air) to provide the public with integrated and personalized dynamic schedules.

Transfer connections with other transit agencies are facilitated through market package APTS7, Multi-modal Coordination.

Market package APTS7 –Multi-modal Coordination

This market package establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Multimodal coordination between transit agencies can increase traveler convenience at transit transfer points and clusters (a collection of stops, stations, or terminals where transfers can be made conveniently) and also improve operating efficiency. Transit transfer information is shared between Multimodal Transportation Service Providers, Transit Agencies, and ISPs.

Notes on architecture representation

The APTS2 Market Package includes many of the traditional service planning and scheduling activities, in addition to the dispatching and operations management functions. Additional information to aid in operations management is provided by connections to traffic management and maintenance and construction management. Information on service levels is communicated to passengers at least at the level of communication with an ISP.

Connection protection is not explicitly mentioned, although it could be implicitly subsumed within the data flow, "approved_corrective_plan" in the architecture flow to vehicle.

Transfer connections with other transit agencies are facilitated through market package APTS7 Multi-modal Coordination. Specifically, architecture flows from Transit Management to the terminators Other Transit Management and Multimodal Transportation Service Provider should also be included, to cover connection protection in these cases.

The architecture flows with traffic management, ISPs, and maintenance and construction tasks are not specifically mentioned in among the BRT features. These flows are part of the APTS2 market package, but not through the given equipment packages. In the ITS Architecture, these subsystems and flows appear in separate equipment packages.

The following is not discussed directly in the BRT or ITS Architecture documentation:

As an option, information processing and communication can also be decentralized to field units (field supervisors) at either fixed or mobile locations. This is not explicitly included in the market package APTS2.

Similarly, data flows to and from specific locations (stations / roadside) are not explicitly included in the architecture, except perhaps as internal communication within the Transit Management subsystem.

Recommendations on architecture representation

The APTS2 market package should be used as a baseline. Architecture flows to and from the traffic, ISP, and maintenance and construction management subsystems will be maintained.

The terminators for Other Transit Management and Multimodal Transportation Service Provider should be included to cover connection protection, and associated architecture flows should be included from the Transit Management subsystem from APTS7.

If the option is considered:

The existing APTS2 market package should be expanded by including a new equipment package for distributed field supervision. This equipment package would be included in the Transit

Management subsystem, but might then require (internal) architecture flows to other Transit Management equipment packages. These are not shown in our rendition of the architecture.

Equipment Packages

Equipment Package	Subsystem
Transit Center Fixed-Route Operations	Transit Management
Transit Vehicle Operator Scheduling	Transit Management
Transit Center Multimodal Coordination	Transit Management
On-board Fixed Route Schedule Management	Transit Vehicle

Architecture Flows

From	To	Architecture Flow
Information Service Provider	Transit Management	transit information request
Maintenance and Construction Management	Transit Management	current asset restrictions
Maintenance and Construction Management	Transit Management	roadway maintenance status
Maintenance and Construction Management	Transit Management	work zone information
Multimodal Transportation Service Provider	Transit Management	multimodal service data
Other Transit Management	Transit Management	transit service coordination
Traffic Management	Transit Management	road network conditions
Transit Management	Information Service Provider	transit and fare schedules
Transit Management	Multimodal Transportation Service Provider	transit multimodal information
Transit Management	Other Transit Management	transit service coordination
Transit Management	Transit System Operators	transit operations status
Transit Management	Transit Vehicle Operator	route assignment
Transit Management	Transit Vehicle	transit schedule information
Transit Management	Transit Vehicle	transit vehicle operator information
Transit System Operators	Transit Management	transit system operator inputs
Transit Vehicle Operator	Transit Management	transit vehicle operator availability
Transit Vehicle Operator	Transit Vehicle	transit vehicle operator inputs
Transit Vehicle	Transit Management	transit vehicle schedule performance
Transit Vehicle	Transit Vehicle Operator	transit vehicle operator display

(3.2) Vehicle Mechanical Monitoring and Maintenance

Description of feature

This feature automatically monitors the condition of transit vehicle engine components via engine sensors and provides warnings of impending (out of tolerance indicators) and actual failures. The feature requires a communication system and on-board mechanical monitoring system that is capable of collecting and transmitting necessary vehicle data.

It also supports automatic transit maintenance scheduling and monitoring. When critical status information is sent to the Transit Management Subsystem, hardware and software in the Transit Management Subsystem processes this data and schedules preventative and corrective maintenance ([1, p.2-55], [2, p.17], [3, p. 7-2]).

Relation to National ITS market package(s): APTS6

Market package APTS6 – Transit Maintenance

This market package supports automatic transit maintenance scheduling and monitoring. On-board condition sensors monitor system status and transmit critical status information to the Transit Management Subsystem. Hardware and software in the Transit Management Subsystem processes this data and schedules preventative and corrective maintenance.

Notes on architecture representation

The general elements of this BRT feature are in the APTS6 market package. However, there is no formal communication with the vehicle operator (for status or warning messages) in the national ITS architecture. One might want a flow to the Transit Vehicle Operator terminator.

There is also no interface of APTS6 with APTS2 to ensure that vehicles are dispatched to minimize service disruptions, when a vehicle must be taken out of service.

Recommendations on architecture representation

The existing APTS6 market package should be enhanced to include dispatching-related equipment packages from APTS2: Transit Center Fixed-Route Operations (Transit Management subsystem); and, Transit Vehicle Operator Scheduling (Transit Management subsystem); and On-board Fixed Route Schedule Management (Transit Vehicle subsystem). Associated architecture flows from APTS2, particularly those between the Transit Vehicle and the Transit Management subsystems, should also be included here The Transit Vehicle Operator terminator should be included, with the architecture flow of “Transit Vehicle Operator Display” (includes maintenance data). An acknowledge message is part of the architecture flow, “Transit vehicle operator inputs”.

Equipment Packages

Equipment Package	Subsystem
Transit Garage Maintenance	Transit Management
Transit Center Fixed-Route Operations	Transit Management
Transit Vehicle Operator Scheduling	Transit Management
On-board Maintenance	Transit Vehicle
On-board Fixed Route Schedule Management	Transit Vehicle

Architecture Flows

From	To	Architecture Flow
Basic Transit Vehicle	Transit Vehicle	transit vehicle measures
Transit Management	Transit System Operators	transit operations status
Transit Management	Transit Vehicle	request for vehicle measures
Transit Management	Transit Vehicle	transit vehicle operator information
Transit Management	Transit Vehicle	transit schedule information
Transit Management	Transit Vehicle Operator	route assignment
Transit System Operators	Transit Management	transit system operator inputs
Transit Vehicle	Transit Management	transit vehicle conditions
Transit Vehicle	Transit Management	transit vehicle schedule performance
Transit Vehicle	Transit Vehicle Operator	transit vehicle operator display
Transit Vehicle Operator	Transit Management	transit vehicle operator availability
Transit Vehicle Operator	Transit Vehicle	transit vehicle operator inputs

(3.3) Vehicle Tracking (with Buses as Traffic Probes)

Description of feature

This feature monitors current transit vehicle location using an Automated Vehicle Location System. The location data may be used to determine the real time schedule adherence and update the transit system’s schedule in real time. This feature allows real-time monitoring of a bus’s movements, control of bus headways, closer schedule adherence (including more effective timed transfers, in conjunction with the Automated Scheduling Dispatch System), and the ability to direct maintenance crews in the event of a vehicle breakdown. Vehicle position may be determined either by the vehicle (e.g., through GPS) and relayed to the infrastructure or may be determined directly by the communications infrastructure. A two-way wireless communication link with the Transit Management Subsystem is used for relaying vehicle position and control measures. Fixed route transit systems may also employ beacons along the route to enable position determination and facilitate communications with each vehicle at fixed intervals. The Transit Management Subsystem processes this information, updates the transit schedule and makes real-time schedule information available to the Information Service Provider. The feature also supports communication of bus tracking information with the Traffic Management

Subsystem, as the buses may serve as vehicle probes in the road network ([1, p.2-56], [2, p.17], [3, p.7-1]).

Relation to National ITS market package(s): APTS1

Market Package APTS1 - Transit Vehicle Tracking

This market package monitors current transit vehicle location using an Automated Vehicle Location System. The location data may be used to determine the real time schedule adherence and update the transit system's schedule in real time. Vehicle position may be determined either by the vehicle (e.g., through GPS) and relayed to the infrastructure or may be determined directly by the communications infrastructure. A two-way wireless communication link with the Transit Management Subsystem is used for relaying vehicle position and control measures. Fixed route transit systems may also employ beacons along the route to enable position determination and facilitate communications with each vehicle at fixed intervals. The Transit Management Subsystem processes this information, updates the transit schedule and makes real-time schedule information available to the Information Service Provider.

Notes on architecture representation

Essentially, the vehicle tracking elements of the BRT feature map directly to the APTS1 market package. The element of buses as traffic probes comes from a separate market package in the ITS architecture. In ATMS02, the Transit Management Subsystem has an architecture flow, "road network probe information", to the Traffic Management Subsystem. In this way, the BRT vehicle provides probe data into traffic management.

Recommendations on architecture representation

APTS1 should be included directly. However, to accommodate the elements of ATMS02, the Traffic Management Subsystem should be included in the architecture representation, with the flow "road network probe information" from Transit Management to Traffic Management. The equipment package "TMC Probe Information Collection" should be included in the Traffic Management Subsystem.

Equipment Packages

Equipment Package	Subsystem
TMC Probe Information Collection	Traffic Management
Transit Center Vehicle Tracking	Transit Management
On-board Transit Trip Monitoring	Transit Vehicle
Vehicle Location Determination	Vehicle

Architecture Flows

From	To	Architecture Flow
Basic Transit Vehicle	Transit Vehicle	transit vehicle measures
Information Service Provider	Transit Management	transit information request
Location Data Source	Vehicle	position fix
Map Update Provider	Transit Management	map updates
Transit Management	Information Service Provider	transit and fare schedules
Transit Management	Map Update Provider	map update request
Transit Management	Traffic Management	road network probe information
Transit Vehicle	Transit Management	transit vehicle location data
Transit Vehicle	Transit Management	transit vehicle schedule performance
Vehicle	Transit Vehicle	vehicle location

(3.4) Archived Data

Description of feature

This feature provides a focused archive that houses data collected and owned by a single agency, district, private sector provider, research institution, or other organization. This focused archive includes data that is collected from vehicle sensors (passenger counters, vehicle maintenance systems, etc.) for future planning purposes or analysis. It provides the basic data quality, data privacy, and meta data management common to all ITS archives and provides general query and report access to archive data users ([1, p. 2-60], [2, p. 18]).

Relation to National ITS market package(s): AD1

Market Package AD1 - ITS Data Mart

This market package provides a focused archive that houses data collected and owned by a single agency, district, private sector provider, research institution, or other organization. This focused archive typically includes data covering a single transportation mode and one jurisdiction that is collected from an operational data store and archived for future use. It provides the basic data quality, data privacy, and meta data management common to all ITS archives and provides general query and report access to archive data users.

Relevant equipment packages:
- Transit Data Collection (in the Transit Management subsystem)
- ITS Data Repository (in the Archived Data Management Subsystem)
- Government Reporting Systems Support (in the Archived Data Management Subsystem)

Notes on architecture representation

This is essentially a local activity within the Transit Management subsystem.

Recommendations on architecture representation

The market package, AD1, essentially covers this BRT feature. Architecture flows from AD1 should also be included, specific to the Transit Management functions. That is, flows to and from terminators are the same as in the existing market package. Flows to and from subsystems should only include the Transit Management and the Archived Data Management subsystems.

Equipment Packages

Equipment Package	Subsystem
Government Reporting Systems Support	Archived Data Management
ITS Data Repository	Archived Data Management
Transit Data Collection	Transit Management

Architecture Flows

From	To	Architecture Flow
Archived Data Administrator	Archived Data Management	archive management requests
Archived Data Management	Archived Data Administrator	archive management data
Archived Data Management	Archived Data User Systems	archived data products
Archived Data Management	Government Reporting Systems	government reporting system data
Archived Data Management	Map Update Provider	map update request
Archived Data Management	Transit Management	archive requests
Archived Data Management	Transit Management	archive status
Archived Data User Systems	Archived Data Management	archived data product requests
Government Reporting Systems	Archived Data Management	government reporting data receipt
Map Update Provider	Archived Data Management	map updates
Transit Management	Archived Data Management	transit archive data

(3.5) Passenger Counting

Description of feature

This feature provides automatic counting of passengers as they enter and exit the BRT vehicle. Data can be used in real-time for vehicle operations or archived for future planning use. Requires additional sensors for counting passengers either on the vehicle or at the station, and ability to store the data on the vehicle until they are downloaded to a central facility, or transfer the information in real time ([1, p. 2-60], [2, p.18], [3, p. 7-2, p. 7-11, p. 7-12]).

Relation to National ITS market package(s): APTS4

Market Package APTS4 - Transit Passenger and Fare Management

This market package manages passenger loading and fare payments on-board transit vehicles using electronic means. It allows transit users to use a traveler card or other electronic payment device. Sensors mounted on the vehicle permit the operator and central operations to determine vehicle loads, and readers located either in the infrastructure or on-board the transit vehicle allow electronic fare payment. Data is processed, stored, and displayed on the transit vehicle and communicated as needed to the Transit Management Subsystem. Two other market packages, ATMS10: Electronic Toll Collection and ATMS16: Parking Facility Management also provide electronic payment services. These three market packages in combination provide an integrated electronic payment system for transportation services.

Relevant equipment packages:

- Transit Center Fare and Load Management (in the Transit Management Subsystem)
- On-board Transit Fare and Load Management (in the Transit Vehicle Subsystem)

Notes on architecture representation

The APTS4 Market Package includes the functionality, but bundles this with electronic fare payment. This would represent one means of implementing a passenger counting system (using a system similar to the electronic payment). Another representation might separate fare payment from passenger counting and load management.

Recommendations on architecture representation

In the case where the architecture integrates passenger counting with fare payment, the existing market package APTS4 is correct.

If passenger counting is run separately from fare payment, the equipment packages within the market package APTS4 should be further subdivided into a “Transit Center Load Management” and an “On-board Transit Load Management”. The fare-related activities should thus be removed from this market package.

There should also be a passenger counting function in the Remote Traveler Support subsystem, considering a passenger counting system off the vehicle (e.g., a turnstile or other in-station counting mechanism). This would mean adding a “Remote Transit Load Management” equipment package to the Remote Traveler Support subsystem.

Architecture flows related to fares should be removed from the existing APTS4 market package, and a new flow from Remote Traveler Support to Transit Management should be added for “remote transit passenger and use data”.

Equipment Packages

Equipment Package	Subsystem
Remote Transit Load Management	Remote Traveler Support
Transit Center Load Management	Transit Management
On-board Transit Load Management	Transit Vehicle

Each of these three equipment packages is a modification of an existing equipment packages in the National ITS Architecture, based on removing fare payment and processing functions from existing equipment packages. Relevant P-specs for these equipment packages include:

Remote Transit Load Management
- 4.7.2.1-Detect Traveler at Roadside
- 4.7.2.2-Determine Traveler Needs at Roadside
- 4.7.2.7-Provide Transit Roadside Passenger Data

Transit Center Load Management
- 4.2.3.5-Manage Transit Operational Data Store
- 4.2.3.7-Provide Interface for Other Transit Management Data

On-board Transit Load Management
- 4.6.1-Detect Traveler on Vehicle
- 4.6.2-Determine Traveler Needs on Vehicle
- 4.6.7-Provide Transit Vehicle Passenger Data

Architecture Flows

From	To	Architecture Flow
Remote Traveler Support	Transit Management	remote transit passenger and use data
Transit Management	Transit System Operators	transit operations status
Transit System Operators	Transit Management	transit system operator inputs
Transit Vehicle	Transit Management	transit vehicle passenger and use data
Traveler	Remote Traveler Support	traveler inputs
Traveler	Transit Vehicle	traveler inputs

The architecture flow for “remote transit passenger and use data” is a new architecture flow defined here, and is based on the existing architecture flow of “transit fare and passenger status”, but removing fare-related data flows. As a result, the “remote transit passenger and used data” architecture flow includes only one data flow: “transit roadside passenger data”.

3.7 Physical Architecture for Feature Category (4) “Fare Collection”

This technology 8group includes methods of electronic fare collection which provide a faster, cashless interface for the passenger. Use of magnetic stripe and smart card technologies are proven and the benefits of electronic payment systems are well-documented. Use of either station-based or vehicle-based fare collection helps reduce dwell times and increase passenger convenience.

(4.1) Station-based Electronic Fare Payment

Description of feature

This feature provides the capability for the traveler to use a common fare medium for all applicable surface transportation services, to pay without stopping, have payment media automatically identified as void and/or invalid and eligibility verified at a BRT stop or station. This may be implemented as a payment instrument reader at a kiosk. This feature also provides the capability to accept collected data required to determine accurate ridership levels and implement variable and flexible fare structures ([1, p. 2-39, 2-40], [3, p.7-12]).

Relation to National ITS market package(s): APTS4

Station-based electronic fare payment is covered as a subset of APTS4.
Market Package APTS4 - Transit Passenger and Fare Management

This market package manages passenger loading and fare payments on-board transit vehicles using electronic means. It allows transit users to use a traveler card or other electronic payment device. Sensors mounted on the vehicle permit the operator and central operations to determine vehicle loads, and readers located either in the infrastructure or on-board the transit vehicle allows electronic fare payment. Data is processed, stored, and displayed on the transit vehicle and communicated as needed to the Transit Management Subsystem.

The description above pertains to vehicle based fare collection only and does not address station based fare collection. However two of the equipment packages used by APTS4 do address station-based fare management. They are:

Remote Transit Fare Management
This equipment package provides the capability for the traveler to use a common fare medium for all applicable surface transportation services, to pay without stopping, have payment media automatically identified as void and/or invalid and eligibility verified. This may be implemented as a payment instrument reader at a kiosk. In addition, capability to provide expansion into other uses for payment medium such as retail and telephone and for off-line billing for fares paid by agencies shall be supported.

Transit Center Fare and Load Management
This equipment package provides the capability to accept collected data required to determine accurate ridership levels and implement variable and flexible fare structures. Support shall be provided for the traveler for use of a fare medium for all applicable surface transportation services, to pay without stopping, have payment media automatically identified as void and/or invalid and eligibility verified, and allow for third party payment. In addition, capability to provide expansion into other uses for payment medium such as retail and telephone and for off-line billing for fares paid by agencies shall be supported. This equipment package also supports

the capability for two-way voice communication between the transit vehicle operator and a facility, two-way data communication between the transit vehicles and a facility, sensor data to be transmitted from the transit vehicles to a facility, and data transmission from individual facilities to a central facility for processing/analysis if desired. This equipment package builds on basic capabilities provided by the Transit Center Tracking and Dispatch equipment package.

Station based electronic fare payment can be access-controlled or barrier free. The existing ITS architecture does not provide an interface with barrier hardware, such as fare gates or turnstiles. An interface should exist between entry/exit control hardware to enable or deny passage based on the status of payment. Multi-use payment media, such as a smart card system, is supported.

Recommendations on architecture representation

Use APTS4 as a basis, but remove the on-board fare collection component (a separate functional category). The result marketing package will consist of *Remote Transit Fare Management* and relevant parts of the *Transit Center Fare and Load Management* only. The new market package descriptions should be drawn from the descriptions of these two equipment packages. Add support for access control hardware, such as fare gates or turnstiles. This should involve the addition of an internal PSpec to the *Remote Transit Fare Management* equipment package. No change to any architecture flow is required.

Minimal Action: Adapt a reduced-functionality version of ATPS4.

Equipment Packages

Equipment Package	**Subsystem**
Remote Transit Fare Management	Remote Traveler Support
Transit Center Fare and Load Management	Transit Management

Architecture Flows

Source	**Architecture Flow**	**Destination**
Financial Institution	transaction status	Transit Management
Information Service Provider	transit information request	Transit Management
Other Transit Management	transit fare coordination	Transit Management
Remote Traveler Support	transit fare and passenger status	Transit Management
Remote Traveler Support	transit interface updates	Traveler
Remote Traveler Support	request for payment	Traveler Card
Transit Management	payment violation notification	Enforcement Agency

Transit Management	payment request	Financial Institution
Transit Management	transit request confirmation	Information Service Provider
Transit Management	transit fare cooordination	Other Transit Management
Transit Management	transit fare information	Remote Traveler Support
Transit Management	transit operations status	Transit System Operators
Transit System Operators	transit system operator inputs	Transit Management
Traveler	traveler inputs	Remote Traveler Support
Traveler Card	payment	Remote Traveler Support

(4.2) Vehicle-based Electronic Fare Payment

Description of feature

This feature manages passenger loading and fare payments on-board transit vehicles using electronic means. It allows transit users to use a traveler card or other electronic payment device. Sensors mounted on the vehicle permit the operator and central operations to determine vehicle loads, and readers located either in the infrastructure or on-board the transit vehicle allows electronic fare payment. Data is processed, stored, and displayed on the transit vehicle and communicated as needed to the Transit Management Subsystem ([1, p. 39, p. 43]).

Relation to National ITS market package(s): APTS4

Market Package APTS4 – Transit Passenger and Fare Management
The description of this market package is included under the discussion on (4.1) Station-based Electronic Fare Payment.

Notes on architecture representation

Coverage is included in APTS4 *Transit Passenger and Fare Management*. Onboard fare payment is represented in the *Onboard Transit Fare and Load Management* Equipment Package, part of APTS4.

Onboard Transit Fare and Load Management (Equipment Package)

This equipment package provides the capability to collect data required to determine accurate ridership levels and implement variable and flexible fare structures. Support shall be provided for the traveler for use of a fare medium for all applicable surface transportation services, to pay without stopping, have payment media automatically identified as void and/or invalid and eligibility verified, and allow for third party payment. In addition, capability to provide expansion into other uses for payment medium such as retail and telephone and for off-line billing for fares paid by agencies shall be supported. This equipment package also supports the capability for two-way voice communication between the transit vehicle operator and a facility, two-way data communication between the transit vehicles and a facility, sensor data to be transmitted from the transit vehicles to a facility, and data transmission from individual facilities to a central facility for processing/analysis if desired. These capabilities require integration with an existing On-board Trip Monitoring equipment package.

As mentioned previously, support exists for a multi-use smart card that can be used across multiple modes of transportation. Support for intermodal "fare integration" is an important requirement for a Fare Payment system in BRT.

Recommendations on architecture representation

A market package can be formed from the *Onboard Transit Fare and Load Management* Equipment Package, and the relevant parts of the *Transit Center Fare and Load Management* Equipment package.

Minimal Action: Adapt a reduced-functionality version of APTS4.

Equipment Packages

Equipment Package	**Subsystem**
On-board Transit Fare and Load Management	Transit Vehicle Subsystem
Transit Center Fare and Load Management	Transit Management

Architecture Flows

Source	**Architecture Flow**	**Destination**
Financial Institution	transaction status	Transit Management
Information Service Provider	transit information request	Transit Management
Other Transit Management	transit fare coordination	Transit Management
Transit Management	payment violation notification	Enforcement Agency
Transit Management	payment request	Financial Institution
Transit Management	transit request confirmation	Information Service Provider
Transit Management	transit fare cooordination	Other Transit Management
Transit Management	transit operations status	Transit System Operators
Transit System Operators	transit system operator inputs	Transit Management

Transit Management	bag tag list	Transit Vehicle Subsystem
Transit Management	fare management information	Transit Vehicle Subsystem
Transit Vehicle Subsystem	fare and payment status	Transit Management
Transit Vehicle Subsystem	request for bad tag list	Transit Management
Transit Vehicle Subsystem	transit vehicle passenger and use data	Transit Management
Transit Vehicle Subsystem	traveler interface updates	Traveler
Transit Vehicle Subsystem	request for payment	Traveler Card
Traveler	traveler inputs	Transit Vehicle Subsystem
Traveler Card	payment	Transit Vehicle Subsystem

3.8 Physical Architecture for Feature Category (5) "Passenger Information"

This technology group includes various methods of providing information to passengers so they can make the best use of their time. Information about vehicle schedules can be provided at the station/stop and/or on the vehicle. Providing8 schedule information to travelers via PDA, mobile phone or similar device, and trip planning can be supported, if there is sufficient need from travelers. All the passenger information functions improve passenger satisfaction, help reduce waiting times, and can increase ridership.

(5.1) Traveler Information at Stations / Stops

Description of feature

For BRT systems, information about the vehicle schedule, next bus information or delays within the system via dynamic message sign can be provided to transit passengers at stations/stops. This requires techniques to predict the vehicle arrival time and the ability to display this information at the station/stop ([1, p. 2-57], [2, p. 17]).

Relation to National ITS market package(s): APTS8

Market package APTS8 – Transit Traveler Information

This market package provides transit users at transit stops and on-board transit vehicles with ready access to transit information. The information services include transit stop annunciation, imminent arrival signs, and real-time transit schedule displays that are of general interest to transit users. Systems that provide custom transit trip itineraries and other tailored transit information services are also represented by this market package.

Notes on architecture representation

The basic components are included in the market package APTS8 – Transit Traveler Information. Specifically, the subsystem, *Remote Traveler Support*, provides access to traveler information at transit stations, transit stops, other sites along travel routes (e.g., rest stops, merchant locations), and major trip generation locations such as special event centers, hotels, office complexes, amusement parks, and theatres. At transit stops, simple displays providing schedule information and imminent arrival signals can be provided. The equipment package, *Remote Transit Information Services*, in this subsystem furnishes transit users with real-time travel-related information at transit stops, multi-modal transfer points, and other public transportation areas. It provides transit users with information on transit routes, schedules, transfer options, available services, fares, and real-time schedule adherence. The architecture flow, *transit information user request*, requests for special transit routing, real-time schedule information, and availability information. The links to the subsystems *Transit Vehicle* and *Personal Information Access* in APTS8 are not needed for this BRT feature.

Equipment packages

Equipment Package	**Subsystem**
ISP Traveler Data Collection	Information Service Provider
Interactive Infrastructure Information	Information Service Provider
Remote Transit Information Services	Remote Traveler Support
Transit Center Information Services	Transit Management

Architecture flows

From	**To**	**Architecture Flow**
Information Service Provider	Transit Management	transit information request
Other Transit Management	Transit Management	transit traveler information coordination
Remote Traveler Support	Transit Management	transit information user request
Remote Traveler Support	Traveler	traveler interface updates (*)
Transit Management	Information Service Provider	transit and fare schedules
Transit Management	Information Service Provider	transit request confirmation (*)
Transit Management	Other Transit Management	transit traveler information coordination
Transit Management	Remote Traveler Support	transit traveler information
Traveler	Remote Traveler Support	traveler inputs (*)

(*) indicates that the architecture flow is not shown in the feature diagram

(5.2) Traveler Information in Vehicles

<u>Description of feature</u>

This feature provides information about next stop, vehicle schedule, transfer or other bus information or delays within the system via dynamic message sign on the vehicle. This requires techniques to predict the vehicle arrival time at the station/stop, receive data on other vehicles along the route and the ability to display the information to transit passengers riding on the vehicle ([1, p. 2-58], [2, p. 18]).

<u>Relation to National ITS market package(s)</u>: APTS8

Market package APTS8 – Transit Traveler Information

The description of this market package is included under the discussion on (5.1) Traveler information at stations/stops.

<u>Notes on architecture representation</u>

This is very similar to the BRT feature (A.1), except that the transit information will be provided on the vehicle. The basic component is in the market package APTS8 – Transit Traveler Information. The subsystem, *Transit Vehicle* with equipment package *Onboard Transit Information Services*, provides access to transit information on the vehicle. This equipment package furnishes en-route transit users with real-time travel-related information on-board a transit vehicle. Current information that can be provided to transit travelers includes transit routes, schedules, transfer options, fares, real-time schedule adherence, current incidents, weather conditions, non-motorized transportation services, and special events. The links to the *Remote Traveler Support* and *Personal Information Access* in APTS8 are not relevant.
Note that the architecture flow "Traveler Inputs" from the "Traveler" terminator to the "Transit Vehicle" subsystem is not shown in the feature diagram. This information link allows a traveler to summon assistance, request travel information, make a reservation, or request any other traveler service.

<u>Equipment packages</u>

Equipment Package	Subsystem
ISP Traveler Data Collection	Information Service Provider
Interactive Infrastructure Information	Information Service Provider
Transit Center Information Services	Transit Management
On-board Transit Information Services	Transit Vehicle

Architecture flows

From	To	Architecture Flow
Information Service Provider	Transit Management	transit information request
Other Transit Management	Transit Management	transit traveler information coordination
Transit Management	Information Service Provider	transit and fare schedules
Transit Management	Information Service Provider	transit request confirmation (*)
Transit Management	Other Transit Management	transit traveler information coordination
Transit Management	Transit Vehicle	transit schedule information
Transit Management	Transit Vehicle	transit traveler information
Transit Vehicle	Transit Management	transit traveler request
Transit Vehicle	Traveler	traveler interface updates
Traveler	Transit Vehicle	traveler inputs (*)

(*) indicates that the architecture flow is not shown in the feature diagram

(5.3) Traveler Information on Person

Description of feature

This feature provides information about vehicle schedule, next bus information or delays within the system via PDA, mobile phone or similar devices used by the traveler. It requires techniques to predict the arrival time at the station/stop, receive data on other vehicles along the route and the ability to display the information to the transit passengers riding on the vehicle. Providing schedule information to travelers via mobile devices requires implementation across the entire transit network ([1, p. 2-58], [2, p. 17]).

At present, there is *no plan* for providing “traveler Information on Person” in BRT, which is partly due to a relatively small number of travelers using appropriate receiving devices at this time.

Relation to National ITS market package(s): APTS8

Market package APTS8 – Transit Traveler Information

The description of this market package is included under the discussion on (5.1) Traveler information at stations/stops, and (5.2) Traveler information on vehicles.

Market package ATIS2 – Interactive Traveler Information

This market package provides tailored information in response to a traveler request. Both real-time interactive request/response systems and information systems that "push" a tailored stream of information to the traveler based on a submitted profile are supported. The traveler can obtain current information regarding traffic conditions, roadway maintenance and construction, transit services, ride share/ride match, parking management, detours and pricing information. A range of two-way wide-area wireless and fixed-point to fixed-point communications systems may be used to support the required data communications between the traveler and Information Service Provider. A variety of interactive devices may be used by the traveler to access information prior to a trip or en route including phone via a 511-like portal, kiosk, Personal Digital Assistant, personal computer, and a variety of in-vehicle devices. This market package also allows value-added resellers to collect transportation information that can be aggregated and be available to their personal devices or remote traveler systems to better inform their customers of transportation conditions. Successful deployment of this market package relies on availability of real-time transportation data from roadway instrumentation, transit, probe vehicles or other means. A traveler may also input personal preferences and identification information via a “traveler card” that can convey information to the system about the traveler as well as receive updates from the system so the card can be updated over time.

Notes on architecture representation

The market packages APTS8 and ATIS2 are used in deploying this feature. The user can obtain the information directly from the Information Service Provider subsystem or indirectly via the Transit Management subsystem, using ATIS2 and APTS8, respectively. The equipment package, Personal Interactive Information Reception, provides the capability to transmit transit information to travelers’ portable devices. This equipment package provides traffic information, road conditions, transit information, yellow pages (traveler services) information, special event information, and other traveler information that is specifically tailored based on the traveler's request and/or previously submitted traveler profile information. The interactive traveler information capability is provided by personal devices including personal computers and personal portable devices such as personal digital assistants (PDAs).

Equipment packages

Equipment Package	**Subsystem**
ISP Traveler Data Collection	Information Service Provider
Interactive Infrastructure Information	Information Service Provider
Personal Interactive Information Reception	Personal Information Access
Transit Center Information Services	Transit Management

Architecture flows

From	**To**	**Architecture Flow**
Information Service Provider	Transit Management	transit information request
Other Transit Management	Transit Management	transit traveler information coordination
Information Service Provider	Personal Information Access	traveler information
Information Service Provider	Transit Management	transit information request
Personal Information Access	Information Service Provider	traveler profile (*)
Personal Information Access	Information Service Provider	traveler request

Personal Information Access	Traveler	traveler interface updates (*)
Personal Information Access	Transit Management	transit information user request
Transit Management	Information Service Provider	transit and fare schedules
Transit Management	Information Service Provider	transit incident information (*)
Transit Management	Information Service Provider	transit request confirmation (*)
Transit Management	Other Transit Management	transit traveler information coordination
Transit Management	Personal Information Access	personal transit information
Traveler	Personal Information Access	traveler inputs (*)

(*) indicates that the architecture flow is not shown in the feature diagram

(5.4) Trip itinerary planning

Description of feature

This feature provides a means for a traveler to request trip information by specifying a trip origin and destination, time and date. It also lets travelers specify their special equipment or handling requirements ([1, p. 2-58], [2, p. 18]).

Relation to National ITS market package(s): ATIS5

Market package ATIS5 – IPS Based Trip Planning and Route Guidance

This market package offers the user trip planning and en-route guidance services. It generates a trip plan, including a multimodal route and associated service information (e.g., parking information), based on traveler preferences and constraints. Routes may be based on static information or reflect real time network conditions. Unlike ATIS3 and ATIS4, where the user equipment determines the route, the route determination functions are performed in the Information Service Provider Subsystem in this market package. The trip plan may be confirmed by the traveler and advanced payment and reservations for transit and alternate mode (e.g., airline, rail, and ferry) trip segments, and ancillary services (e.g., parking reservations) are accepted and processed. The confirmed trip plan may include specific routing information that can be supplied to the traveler as general directions or as turn-by-turn route guidance depending on the level of user equipment.

Notes on architecture representation

The market package, ATIS5 is used to deploy this feature. The equipment package, *Personal Trip Planning and Route Guidance*, provides the key support. This equipment package provides a personalized trip plan to the traveler. The trip plan is calculated by the *Information Service Provider* (ISP) subsystem based on preferences and constraints supplied by the traveler and provided to the traveler for confirmation. Reservations and advanced payment may also be processed by this equipment package to confirm the trip plan. Coordination with the ISP may continue during the trip so that the route plan can be modified to account for new information. Many equipment configurations are possible including systems that provide a basic trip plan to the traveler as well as more sophisticated systems that can provide transition by transition guidance to the traveler along a multi-modal route. Devices represented by this equipment package include desktop computers at home, work, or at major trip generation sites, plus personal portable devices such as PDAs and pagers. The architecture flow, *traveler profile*, from subsystem *Personal Information Access* to *ISP* provides information about a traveler's equipment capabilities. This flow is not shown in the feature diagram. Those links to the subsystems, *Vehicle* and *Remote Traveler Support*, in ATIS5 are not relevant.

Equipment packages

Equipment Package	Subsystem
Infrastructure Provided Trip Planning	Information Service Provider
ISP Traveler Data Collection	Information Service Provider
Personal Location Determination	Personal Information Access
Personal Trip Planning and Route Guidance	Personal Information Access

Architecture flows

From	To	Architecture Flow
Information Service Provider	ISP Operator	ISP operating parameters (*)
Information Service Provider	Map Update Provider	map update request (*)
Information Service Provider	Multimodal Transportation Service Provider	multimodal information request
Information Service Provider	Other ISP	ISP coordination (*)
Information Service Provider	Personal Information Access	trip plan
Information Service Provider	Transit Management	selected routes
Information Service Provider	Transit Management	transit information request
ISP Operator	Information Service Provider	ISP operating parameter updates (*)
Location Data Source	Personal Information Access	position fix
Map Update Provider	Information Service Provider	map updates (*)
Map Update Provider	Personal Information Access	map updates (*)
Multimodal Transportation Service Provider	Information Service Provider	multimodal information
Other ISP	Information Service Provider	ISP coordination (*)
Personal Information Access	Information Service Provider	traveler profile (*)
Personal Information Access	Information Service Provider	trip confirmation
Personal Information Access	Information Service Provider	trip request
Personal Information Access	Map Update Provider	map update request (*)
Personal Information Access	Traveler	traveler interface updates (*)
Transit Management	Information Service Provider	transit and fare schedules
Traveler	Personal Information Access	traveler inputs (*)

(*) indicates that the architecture flow is not shown in the feature diagram

3.9 Physical Architecture for Feature Category (6) "Safety and Security"

This technology group includes functions that enhance BRT operations. Use of silent alarms and monitoring systems can increase security of BRT operation. Alarms installed on BRT vehicles are activated by the driver. A message such as "call 911" can be displayed on the exterior sign board for others to notice, or messages can be sent back to the operations centre to indicate an emergency problem. Surveillance of the vehicle can be supported by use of microphone or CCTV camera. Data are transmitted to an operations centre to monitor.

(6.1) Silent alarms

<u>Description of feature</u>

These are alarms installed on the BRT vehicle that can be activated by the BRT vehicle driver. A message such as "call 911" can be displayed on the exterior sign board for others to see or messages can be sent back to the operations centre to indicate an emergency problem ([1, p. 2-59), [2, p. 18]).

<u>Relation to National ITS market package(s)</u>: EM3

Market package EM3 – Mayday and Alarms Support

This market package allows the user (driver or non-driver) to initiate a request for emergency assistance and enables the Emergency Management Subsystem to locate the user, gather information about the incident, and determine the appropriate response. The request for assistance may be manually initiated or automated and linked to vehicle sensors. This market package also includes general surveillance capabilities that enable the Emergency Management Subsystem to remotely monitor public areas (e.g., rest stops, parking lots) to improve security in these areas. The Emergency Management Subsystem may be operated by the public sector or by a private sector telematics service provider.

<u>Notes on architecture representation</u>

The basic components are included in the market package EM3 – Mayday and Alarms Support. The equipment package, *Vehicle Mayday I/F*, of the subsystem *Vehicle* provides the key support. This equipment package provides the capability for drivers or collision detection sensors to report an emergency and summon assistance. This equipment package includes the on-board collision detection sensors, a mechanism for the driver to summon assistance, and two-way communications with a service provider. To implement the BRT feature, we will define a new equipment package named *Transit Vehicle Mayday I/F* for the subsystem *Transit Vehicle*. This new equipment package excludes the on-board detection sensors. The equipment package, *Mayday Support*, receives Mayday messages from transit vehicles, determines an appropriate response, and either uses internal resources or contacts a local agency to provide that response. The nature of the emergency is determined based on the information in the mayday message as well as other inputs. This package effectively serves as an interface between automated mobile mayday systems and the local public safety answering point for messages which require a public safety response. The equipment package, *Center Secure Area Alarm Support*, receives transit vehicle operator alarm messages, notifies the system operator, and provides acknowledgement of alarm receipt back to the operator. The alarms received can be generated by silent or audible alarm systems installed on transit vehicles. The nature of the emergency may be determined based on the information in the alarm message as well as other inputs. The links to the subsystems, *Remote Traveler Support* and *Personal Information Access*, in EM3 are not relevant to this BRT feature.

Equipment packages

Equipment Package	Subsystem
Center Secure Area Alarm Support	Emergency Management
Mayday Support	Emergency Management
Transit Vehicle Location Determination	Transit Vehicle
Transit Vehicle Mayday I/F	Transit Vehicle

The two new equipment packages for the subsystem, Transit Vehicle, are modifications of the existing equipment packages for the subsystem, Vehicle, in the market package EM3. In the equipment package, Transit Vehicle Mayday I/F, we can exclude the "collision detection" process that is associated with the equipment package, Vehicle Mayday I/F. The Pspecs for these two new equipment packages are listed.

Transit Vehicle Location Determination
- 6.7.1.3- Process Vehicle Location Data

Transit Vehicle Mayday I/F
- 3.3.1-Provide Communications Function
- 6.7.1.2-Provide Driver Guidance Interface
- 6.7.2.1-Build Driver Personal Security Message
- 6.7.2.2-Provide Driver In-vehicle Communications Function
- 6.7.3.3-Provide Driver Information Interface

Architecture flows

From	To	Architecture Flow
Basic Vehicle	Transit Vehicle	basic vehicle measures
Driver	Transit Vehicle	request for service
Emergency Management	Emergency System Operator	emergency operation status
Emergency Management	Other emergency Management	incident report
Emergency Management	Transit Vehicle	emergency acknowledgement
Emergency Management	Transit Vehicle	emergency data request
Emergency System Operator	Emergency Management	emergency operations inputs
Location data source	Transit Vehicle	position fix (*)
Transit Vehicle	Driver	driver updates
Transit Vehicle	Emergency Management	emergency notification

(*) indicates that the architecture flow is not shown in the feature diagram

(6.2) Voice and video monitoring

Description of feature

This feature provides surveillance of the vehicle, by use of microphone or CCTV camera. Data can be sent to an operations centre to monitor ([1, p. 2-58], [2, p. 18]).

Relation to National ITS market package(s): APTS5

Market package APTS5 – Transit Security

This market package provides for the physical security of transit passengers and transit vehicle operators. On-board equipment is deployed to perform surveillance and sensor monitoring in order to warn of potentially hazardous situations. The surveillance equipment includes video (e.g., CCTV cameras), audio systems and/or event recorder systems. The sensor equipment includes threat sensors (e.g., chemical agent, toxic industrial chemical, biological, explosives, and radiological sensors) and object detection sensors (e.g., metal detectors). Transit user or transit vehicle operator activated alarms are provided on-board.
The surveillance and sensor information is transmitted to the Emergency Management Subsystem. On-board alarms, activated by transit users or transit vehicle operators are transmitted to both the Emergency Management Subsystem and the Transit Management Subsystem, indicating two possible approaches to implementing this market package.

Notes on architecture representation

The basic components are included in the market package APTS5 – Transit Security. The main component is the equipment package, *On-board Transit Security*, for the subsystem, *Transit Vehicle*. This equipment package provides security and safety functions on-board the transit vehicle. It includes surveillance and sensor systems that monitor the on-board environment, silent alarms that can be activated by transit user or vehicle operator, operator authentication, and a remote vehicle disable function. The surveillance equipment includes video (e.g. CCTV cameras), audio systems and/or event recorder systems. The sensor equipment includes threat sensors (e.g. chemical agent, toxic industrial chemical, biological, explosives, and radiological sensors) and object detection sensors (e.g. metal detectors). Since this BRT feature is not concerned with emergency response, the equipment package, *Emergency Response Management*, in the subsystem, *Emergency Management*, is not needed in the implementation. The link to the *Remote Traveler Support* subsystem in APTS5 that monitors secure areas in the transportation system that are frequented by travelers (e.g., transit stops) is not relevant. The *Security Monitoring Subsystem* for securing and monitoring facilities is also not needed.

Equipment packages

Equipment Package	Subsystem
Center Secure Area Alarm Support	Emergency Management
Center Secure Area Sensor Management	Emergency Management
Center Secure Area Surveillance	Emergency Management
Transit Center Security	Transit Management
On-board Transit Security	Transit Vehicle

Architecture flows

From	To	Architecture Flow
Emergency Management	Transit Vehicle	alarm acknowledge
Emergency Management	Transit Vehicle	secure area sensor control
Emergency Management	Transit Vehicle	secure area surveillance control
Transit Management	Transit Vehicle	alarm acknowledge
Transit Management	Transit Vehicle	transit vehicle operator authentication update
Transit Vehicle	Emergency Management	alarm notification
Transit Vehicle	Emergency Management	secure area sensor data
Transit Vehicle	Emergency Management	secure area surveillance data
Transit Vehicle	Emergency Management	transit vehicle location data
Transit Vehicle	Transit Management	alarm notification
Transit Vehicle	Transit Management	transit vehicle location data
Transit Vehicle	Transit Management	transit vehicle operator authentication information
Transit Vehicle	Transit Vehicle Operator	transit vehicle operator display (*)
Transit Vehicle	Traveler	traveler interface updates (*)
Traveler	Transit Vehicle	traveler inputs (*)

(*) indicates that the architecture flow is not shown in the feature diagram

4. Logical Layer of BRT Architecture

The Logical Layer of the BRT Architecture is analogous to the Logical Architecture in the National ITS Architecture. The Logical Layer is defined in terms of implementation independent processes that inter-communicate and work together to provide a desired functionality.

The logical architecture is detached from the physical implementation of the system, instead decomposing the functionality, or services of the system into processes, or process specifications. Sharing the structure of the ITS Logical Layer, the BRT Logical Layer is constructed from Processes, Terminators and Data Flows. As part of this functional decomposition, a distinction is first made between elements within the system and outside of the system. The sensors, computers and human operators within the system form the entry and exit points which we call terminators. The elements located outside of the system, or terminators, correspond directly to the terminators defined in the physical architecture. In the BRT context, examples of such external terminators include travelers, the transit vehicle, and other vehicles on the roadway. In this example, the transit vehicle is excluded from the ITS architecture on the basis that ITS represents the intelligent systems which provided added functionality to the basic vehicle. The basic mechanical functionality of the vehicle itself, to provide propulsion, to initiate and terminate movement, is therefore not part of the intelligent system, but is rather, an entity that interacts with the ITS architecture.

Interaction between internal processes and external terminators in the ITS architecture are defined using data flow diagrams. Processes at the lowest level are known as process specifications, or pspecs, and are aggregated into higher order processes. Processes are linked by data flows, which represent a flow of information between intercommunicating processes. These data flows are abstract data structures defined through a description of data to be conveyed, without reference to a specific format to which the data must conform. Such specification is left in the domain of the standards such as NTCIP.

4.1 Extracting the logical layer from the National ITS Architecture

In the practical, deployment centric perspective taken in the development of this BRT architecture, where emphasis is placed on the integration of specific BRT services as tangible components, with relation to the deployment of ITS technologies, the Logical Layer is treated as a derivative viewpoint. This approach is the opposite of that taken in the development of the National ITS architecture, where user service requirements are first defined and laid out in terms of logical processes, and the physical architecture is superimposed as an overlaid on top of the logical model.

The Market Package model used in the development of the BRT architecture lends naturally to using the physical architecture as a starting point. Under this model, the purpose of the logical layer is to provided additional details regarding the

Just as the physical layer of the BRT architecture is formulated upon the physical ITS architecture, the logical BRT architecture is also formed on the basis of the logical ITS architecture. Having defined the physical architecture of each of the BRT features in Section 3.4 -3.9, their logical architecture can be constructed. However, the derivative nature of such a logical architecture implies that the authoritative architecture is the physical architecture and the logical layer representation is present primarily to serve as additional reference in the decision making process.

4.2 Extension of the ITS Architecture Database for BRT

<u>Structure of the ITS architecture</u>

An understanding of the relational structure of the ITS architecture is necessary in order to adapt the database. However, existing documentation for the National ITS architecture sheds no useful information. The following is a summary of the results found in reverse-engineering the ITS database.

Architecture flow triplets

The ITS defines architecture flows as simply flows. For our purpose, an architecture flow triplet is defined by the source, flow name, and destination. Flows with the same flow name but different (source, destination) pairs are considered to be separate flows.

Properties of architecture flows triplets

1. An architecture flow triplet is an architecture flow name associated with an originating subsystem and a terminating subsystem. Note that the entity associated with the terminal of an architecture flow is a subsystem, not an equipment package.
2. Each architecture flow name may have multiple source-destination combinations. Each combination constitutes a separate and distinct architecture flow triplet.
3. Architecture flow triplets are an aggregation of data flows. For a data flow to be aggregated within an architecture flow triplet, the source of that dataflow (a pspec) must fall within the subsystem that forms the origin of the parent architecture flow triplet. Likewise the destination of a data flow must be consistent with the destination subsystem of its parent architecture flow triplet.
4. Architecture flow triplets may take a terminator as either its source or destination. An architecture flow triplet cannot have a terminator at each end, as such a piece of information (flowing between two terminators) will play no part in the architecture and should not be part of the architecture at all.

Properties of Equipment Packages

1. Each equipment packages is uniquely defined by a list of pspecs and a list of architecture flow triplets (AFT).
2. Each equipment package is assigned to one and only one of the 22 subsystems. In other words, the equipment packages partition the subsystems.
3. The pspecs defined in an equipment package must be consistent with the AFT defined in the same equipment package. That is, for a pspec to be included in an equipment package, that pspec must be either the source of one or more outgoing data flows attached to an included AFT or AFTs, or, in the same manner, the destination of an incoming dataflow.

BRT features and market packages

Because BRT features are to be modeled after Market Packages, the technical formulation of market packages must be examined in order to develop a systematic method for incorporating BRT features into the database.

Irreducibility of BRT feature descriptions

BRT packages are defined by a list of equipment packages, and a list of AFTs. It would be possible to create a BRT function based solely on a list of equipment packages, and show that there is a resulting list of AFT's that is dependent on the choice of equipment packages and the composition of those equipment packages. However the result may include flows that do not bear relevance to the concerned BRT feature.

Creation of BRT Packages

Equipment packages form the basis for a new BRT feature. Before a BRT feature can be implemented, the required equipment packages need to exist. At this point the equipment packages need not be customized for any architecture flows that have been planned for the BRT feature. In fact, if a new equipment package needs to be created for the BRT feature, one can, at this point, simply create a "shell" equipment package, that is, an equipment package with just a name and no internal structure, that is, no pspecs and no flows.

> *First establish a list of all equipment packages to be used in a BRT feature. This list of equipment packages may be a simple duplicate of corresponding packages in the National ITS Architecture, or it may be original. If an original equipment package is created, its pspec and ATP associations may remain blank for the moment.*

While in practice, BRT features are often developed as a combination of existing market packages, this practice has not been directly supported, as the recombination of preexisting market packages (which are, themselves, collections of equipment packages) creates an additional layer of complexity to reconcile. BRT features are created independent of existing market packages. *BRT features are defined in terms equipment packages, not market packages.*

> *In the BRT feature-equipment package mapping table, gradually add equipment package entries for the BRT feature being created. An update query, as addressed below, is run after each addition to recreate the mapping table.*

This mapping table is compiled by looking at each of the equipment packages associated with the BRT function being constructed.

When run, the update query will only add rows. Existing rows will not be replaced (notwithstanding the state of the selected field). All selected fields are initialized true. The update query also generates separate BRT feature-pspec table, which can be edited in the same manner as the BRT feature-AFT table.

At this point, a separate, temporary query can be executed for the BRT feature being created. The list of flows is then inspected manually. Extraneous or unwanted flows are removed. If a desired flow is missing, it must be added to an equipment package, and the database must then be updated. **Flows cannot be associated directly to a BRT feature.** AFTs must be inherited by a BRT feature from an included equipment package. An inherited flow may then be left included, or removed, if deemed unneeded.

> *In the equipment package-flows table, add the required architecture flow triplets to the corresponding equipment packages. If the ATP uses a new flow name, the architecture flow definition table must also be updated, with the new flow name.*

The update query is rerun, as many times as necessary to reflect all changes in the BRT feature-AFT mapping table. Deselect flows to discard as necessary. Note that changes made to an equipment package will be propagated through to all BRT features using that equipment package. Extraneous flows may result in previously edited BRT features if an equipment package is modified at a later point. To avoid this problem, and the tedious operation of inspecting previously defined BRT features for undesired new flows, flows should be added to equipment packages at the earliest point possible.

This policy of editing only equipment package definitions, and then using the update query to propagate the changes through to the BRT feature level ensures consistency between equipment package definitions and BRT feature definitions.

An automated report can be generated. All the cross references are now present to create report with the following information,
1) For each BRT feature - the ATPs associated with that BRT feature, including the source and destination subsystems. This will be consistent with the architecture flows developed in the physical architecture
2) For each ATP, a list of relevant data flows is listed.

The logical architecture created up to this point can be examined and further changes can be made to both the equipment packages and the architecture flows and ATPs if necessary.

The follow filters can be applied on the list data flows to pare it down to the most consistent set possible. However, this may also erase data flows that are otherwise relevant to the ATP they have been associated with. In the interest of maximizing the utility of the result it may be necessary to omit one or more of the filters. The National ITS architecture serves as a foundation and strict adherence to the framework in this instance is neither necessary nor beneficial.

i) If the dataflow is not associated with one of the architecture flows (flow names, not AFT) contained in the BRT feature-AFT table, the dataflow is either discarded or at least one architecture flow must be amended to include the dataflow.
ii) For each remaining dataflow, we look at its associated architecture flow, and the AFTs using that flow name in the BRT feature-AFT table. If the pspecs forming the source and destination of the dataflow are not consistent with one of the AFTs in the current equipment package, the dataflow may be discarded. In other words, assume that the source pspec of the dataflow is associated with subsystem A, and the destination dataflow of the pspec is associated with subsystem B, and that the dataflow itself is part of architecture flow C, there must exist an AFT entry (A,B,C) in the BRT feature-AFT table, or the dataflow must be discarded. If the dataflow flows only between a pspec and a terminator, the terminator must make the match in the same fashion.
iii) If neither the source nor destination of the dataflow is one of the pspecs in the BRT feature-pspec table, the dataflow is discarded.
iv) If both the source and destination of the dataflow are in the BRT-AFT table, the dataflow is marked an Internal Dataflow. In generating the report this can be achieved by running a separate query.

v) In the situation that one end of the dataflow is a pspec included in the equipment package definition, and the other end is a pspec not included in the equipment package definition, by rule ii above, the latter pspec must still consistent with the AFT corresponding to the data flows. The dataflow is marked an External Dataflow.

i) If one end of the dataflow is a pspec included in the BRT-AFT table, and the other end is a terminator. The dataflow is marked an External Dataflow.

The report is then again inspected manually. Missing pspecs and data flows can be added (at the source) and the report can be regenerated.

<u>Summary - reconstituting the database after modification to EP or AFT associations</u>

1) We begin with a list of equipment packages defined for our BRT feature. Each of these equipment packages is linked to a set of architecture flows flowing either in or out of the equipment package. No distinction is made at this stage about the source (for in incoming flow), or destination (for an outgoing flow) of these architecture flows. In other words these flows have not yet been defined into triplets.

2) We take the information in 1) above and extract from it a list of all architecture flows bridging the equipment packages included in the defined BRT feature. To do this, for each incoming flow into each equipment package, we inspect the source to see if the flow originates from an equipment package that is also part of our BRT feature. We aggregate the results to create unique set of these internal architecture flow triplets.

3) We add to our set of ATPs all flows that either originate from an equipment package within our BRT feature and terminate at a terminator (any terminator), or originate from any external terminator and terminate at an equipment package within our BRT feature definition.

4) At this stage, we have a comprehensive list of ATPs associated with our BRT feature. Data flows are associated with this list by referencing the connection between dataflow and architecture flows. No filter is put on the source and destination pspecs of the data flows, meaning that it is possible for a data flow to be included even though neither the source nor destination pspecs are associated with the corresponding source or destination equipment packages. Enforcing the correspondence between source and destination pspecs and equipment packages leaves filters out many important data flows. Furthermore, some architecture flow triplets may be left with no associated flows at all.

5 Conclusions and Next Steps

This research on the development of BRT architecture has shown how one might build on the existing National ITS Architecture to incorporate a number of important BRT features. In some cases, the features in BRT map directly to market and equipment packages in the existing architecture; in other cases, major modifications and additions to the National ITS Architecture are necessary to support functions within the realm of BRT.

5.1 Conclusions

The primary contributions of this research have really been two-fold. First, the research has illustrated an incremental approach to expanding an existing architecture (the National ITS Architecture) to a relatively new set of features (within BRT). This method suggests a helpful means of approaching this important systems engineering task when there is already a well-developed architecture. The use or adaptation of existing Equipment Packages, P-specs, and data flows to construct new features (or "Market Packages") shows promise in facilitating inclusion of these features into a national or regional architecture. In this regard, the methodology proposed in this report could be easily extended to other features that might be added to the National ITS Architecture. We will be interested in working with the National ITS Architecture Development Team to adapt our approach in expanding the ITS Architecture to include BRT architecture.

Second, the research has resulted in a preliminary analysis of the system engineering needs for BRT more specifically. While this result is preliminary, it does provide some initial input to the continuing process of developing a National ITS Architecture. The development of the National ITS Architecture is an open process, facilitating dialog among both system engineers and the broader BRT community, including technology vendors and potential deployment agencies of that technology. The hope is that this preliminary analysis will provide an important launching point for continued development of BRT architecture. Further development needs to include an examination of the architecture with respect to the communication requirements and existing reference standards. It will also be necessary to carefully study the implementation issues considering the available technologies.

5.2 Next Steps

In the meantime, for transit agencies that are considering BRT, the proposed architecture provides an important and unifying framework that can be useful for further development of BRT systems. We recommend agencies that are currently considering the implementation of BRT features consider their architecture carefully, in light of the proposed equipment packages and architecture flows recommended here. More detailed aspects of the proposed architecture, including P-specs and data flows, can also be considered for implementation.

In the short term, we recommend that Caltrans and transit agency champions in California forward the recommended BRT features, and the preliminary architecture outlined here, to the team developing the National ITS Architecture. The process for incorporating new features (or "user services") in the National ITS Architecture is consensus-driven, but can also be relatively time-consuming. Therefore, we believe it is of critical importance that the National ITS Architecture development team begin work on these BRT features as soon as possible. We expect the preliminary work outlined in this report will serve as preliminary ideas to support the development work. More specifically, this work can leverage the proposed list of BRT features, the equipment packages and architecture flows, and the detailed P-specs and data flows offered in this report. Specific elements of the proposed logical architecture could also be used by the National Architecture development team.

The incorporation of BRT features into the National ITS Architecture will ultimately serve transit agencies in a number of ways. For transit agencies interested in implementing BRT, both high-level planning tools and more technical information could be provided by the National ITS Architecture. In the planning realm, the Turbo Architecture™ tool ([6]) provides a high-level representation of ITS architecture elements, including market packages, equipment packages, and architecture flows. Turbo Architecture is an important tool that can be used by departments of transportation and metropolitan planning organizations to aid in integrating BRT features into regional ITS architectures.

The incorporation of BRT into the National ITS Architecture will also serve two other specific purposes. For system engineers and system designers, the more detailed and consensus physical and logical architectures can be used to design technologies and system requirements that meet the needs of BRT features. Also, these details can ultimately be used to support the development of standards for interfaces in the architecture.

In parallel to this effort on BRT architecture development, a versatile tool is being developed to provide a framework for determining optimal deployment phases in a step-by-step iterative and integrated fashion. The incorporation of the proposed BRT architecture into this deployment tool will enable users, primarily transit agencies, to more fully understand the system architecture requirements and the associated tradeoff agencies will inevitably encounter during the deployment phasing process. It will also help to determine (1) how many stages the deployment plan for BRT systems may need, (2) what BRT elements should be included in each stage, and (3) when each stage should be implemented. The benefits of this improved tool include reduction in design complexity and time, systematic generation of cost-effective schedules for deploying BRT services, and the ease of adding modules for future planning

References

[1] Roderick Diaz, Mark Chang, Georges Darido, Eugene Kim, Donald Schneck, Matthew Hardy, James Bunch, Michael Baltes, Dennis Hinebaugh, Lawrence Wnuk, Fred Silver, and Sam Zimmerman, *Characteristics of Bus Rapid Transit for Decision-Making*, Report FTA-VA-26-7222-2004.1, Prepared for the Office of Research, Demonstration, and Innovation, Federal Transit Administration, US Department of Transportation, August 2004.

[2] Mitretek Systems, *ITS Enhanced Bus Rapid Transit*, Report FTA-DC-26-7075-2003.1, Prepared for the Office of Research, Demonstration, and Innovation, Federal Transit Administration, US Department of Transportation, June 2003.

[3] Herbert S. Levinson, Samuel Zimmerman, Jennifer Clinger, James Gast, Scott Rutherford, and Eric Bruun, *Bus Rapid Transit: Volume 2: Implementation Guidelines*, TCRP Report 90, Volume 2, Transit Cooperative Research Program (TCRP), Washington, DC, 2003.

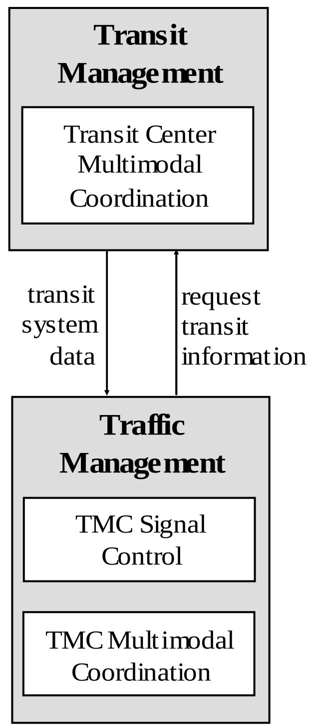
[4] National ITS Architecture (version 5.1) website: http://www.iteris.com/itsarch/

[5] Hong K. Lo, Mark Hickman, and Stein Weissenberger, "A Structured Approach for ITS Architecture Representation and Evaluation", *Proceedings of the IEEE 6th International Conference on Vehicular Navigation and Information Systems*, Seattle, pp. 442-449, July 1995.

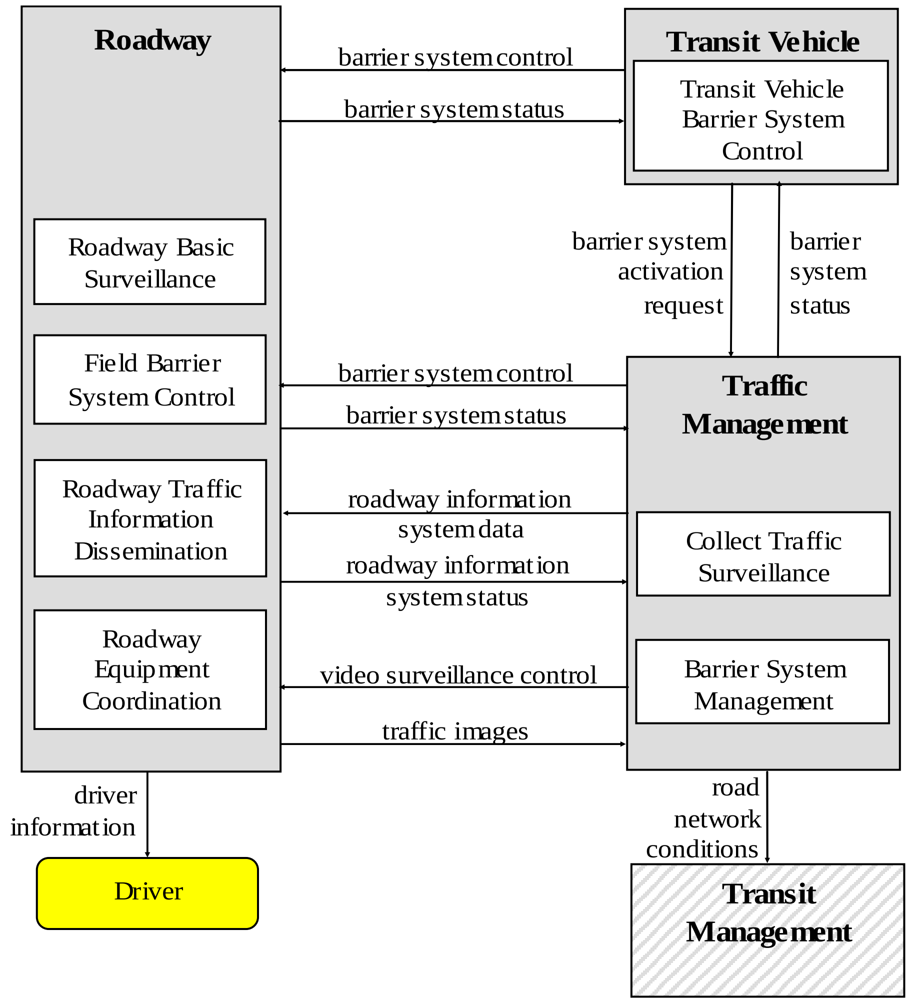
[6] Turbo Architecture™, http://www.iteris.com/itsarch/html/turbo/turbooverview.htm. Accessed June 2, 2005.

Appendix: Feature Diagrams for BRT Physical Architecture

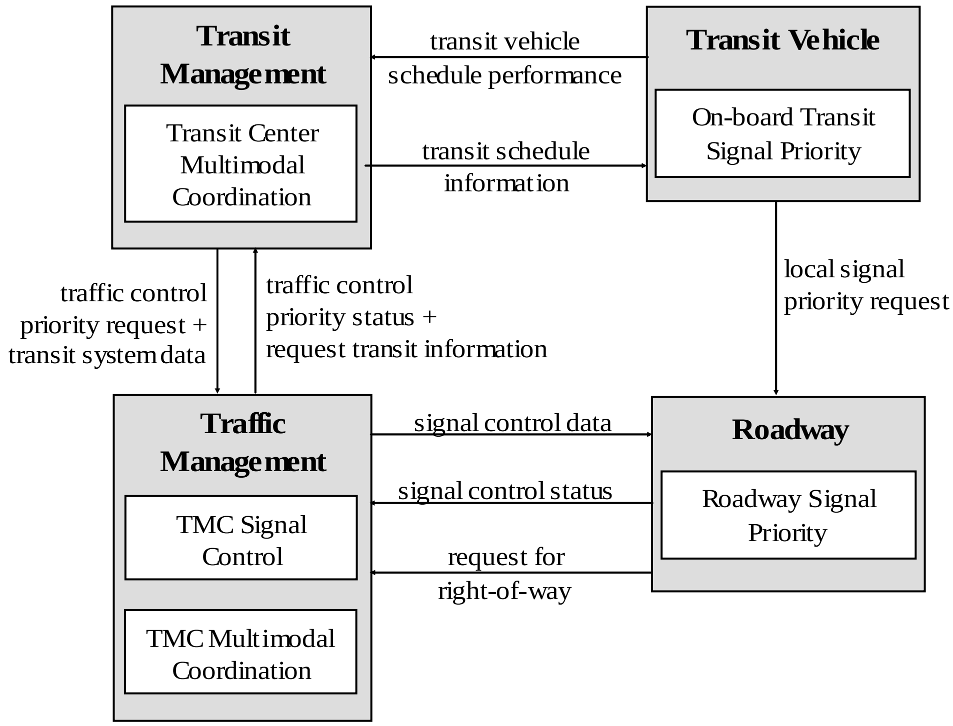
Feature diagram for "(1.1) – "Signal Timing/Phasing"



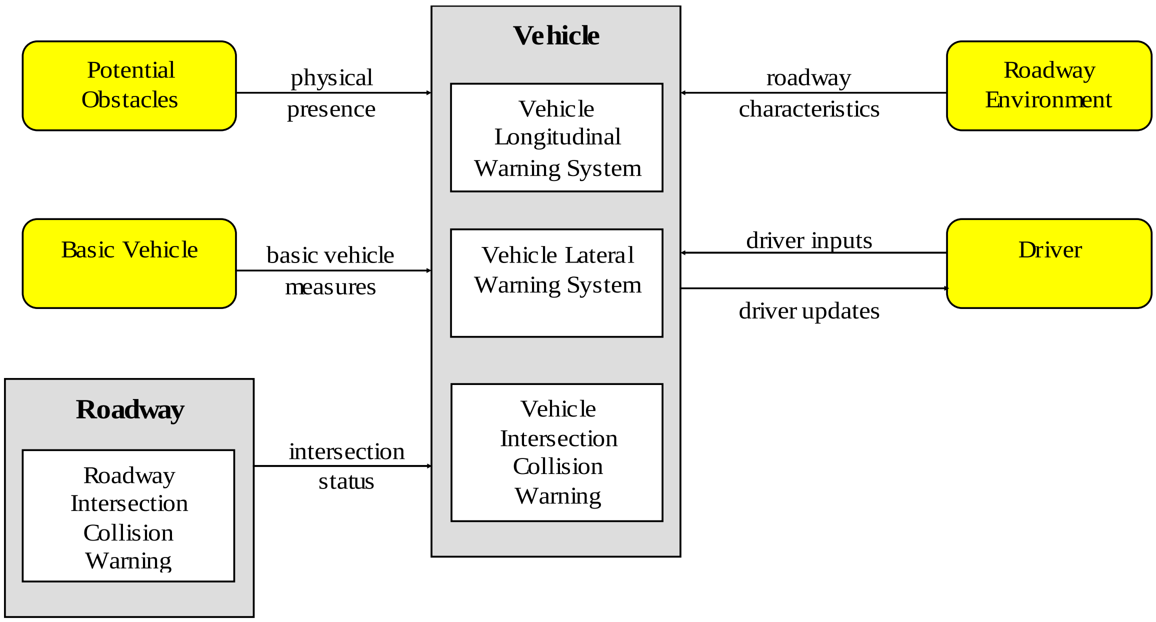
Feature diagram for "(1.2) – "Station and Lane Access Control"



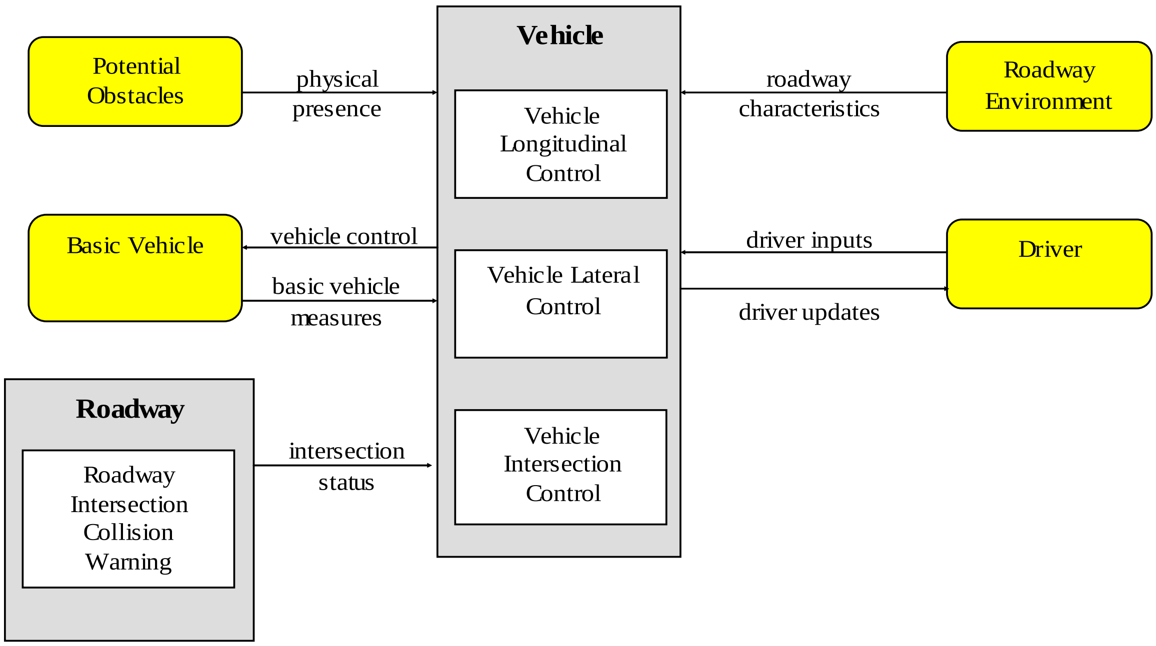
Feature diagram for “(1.3) – “Transit Signal Priority”



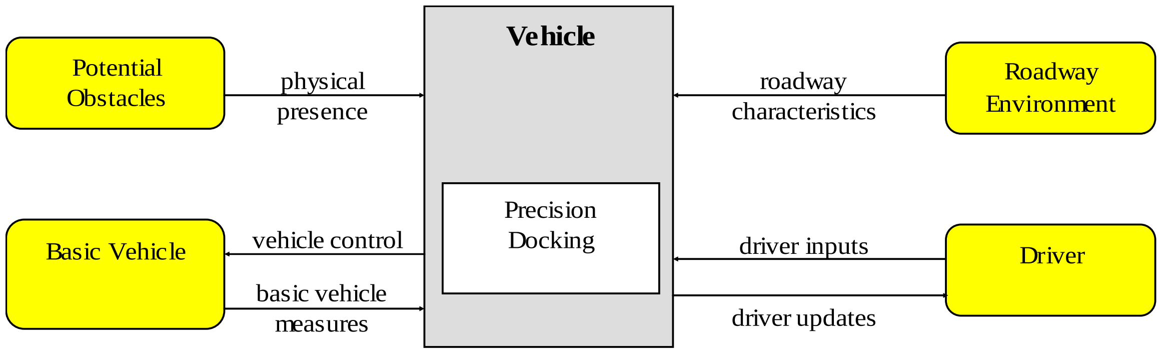
Feature diagram for “(2.1) – “Collision Warning”



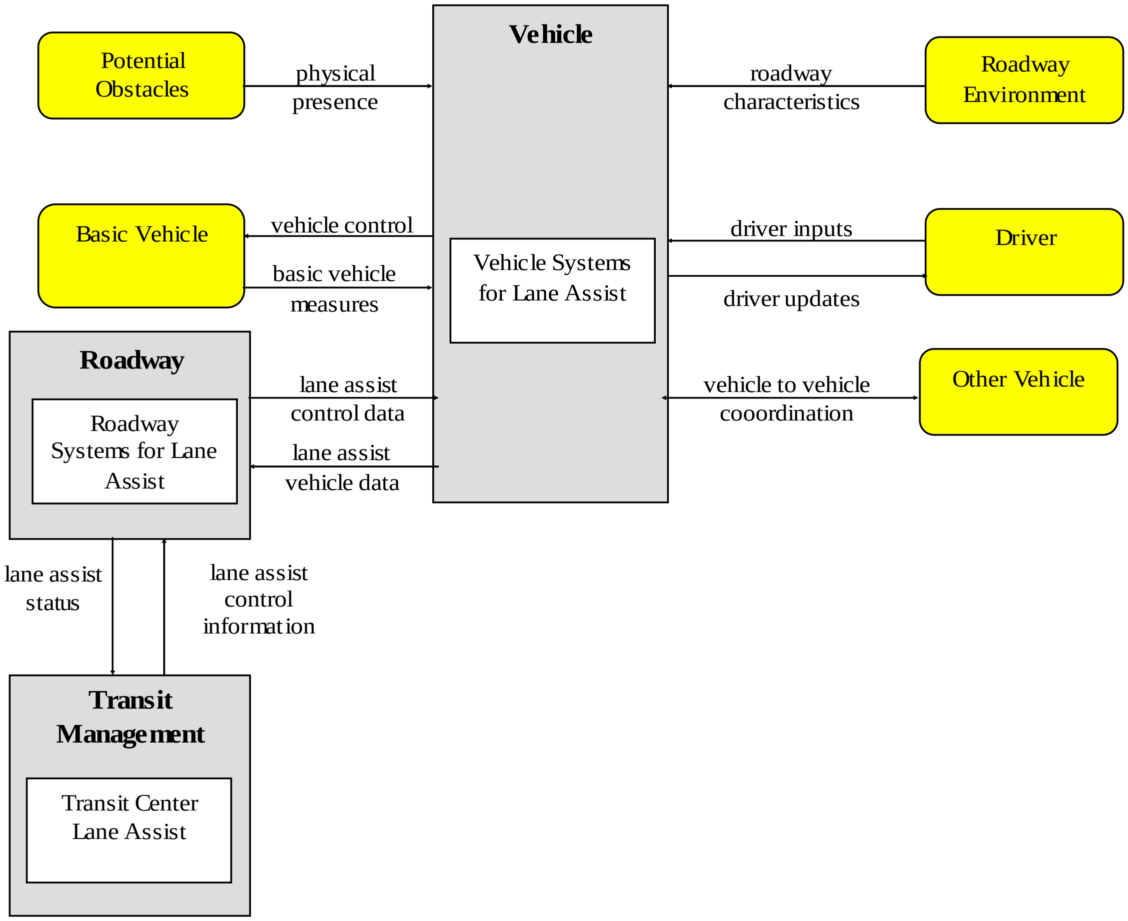
Feature diagram for “(2.2) – “Collision Avoidance”



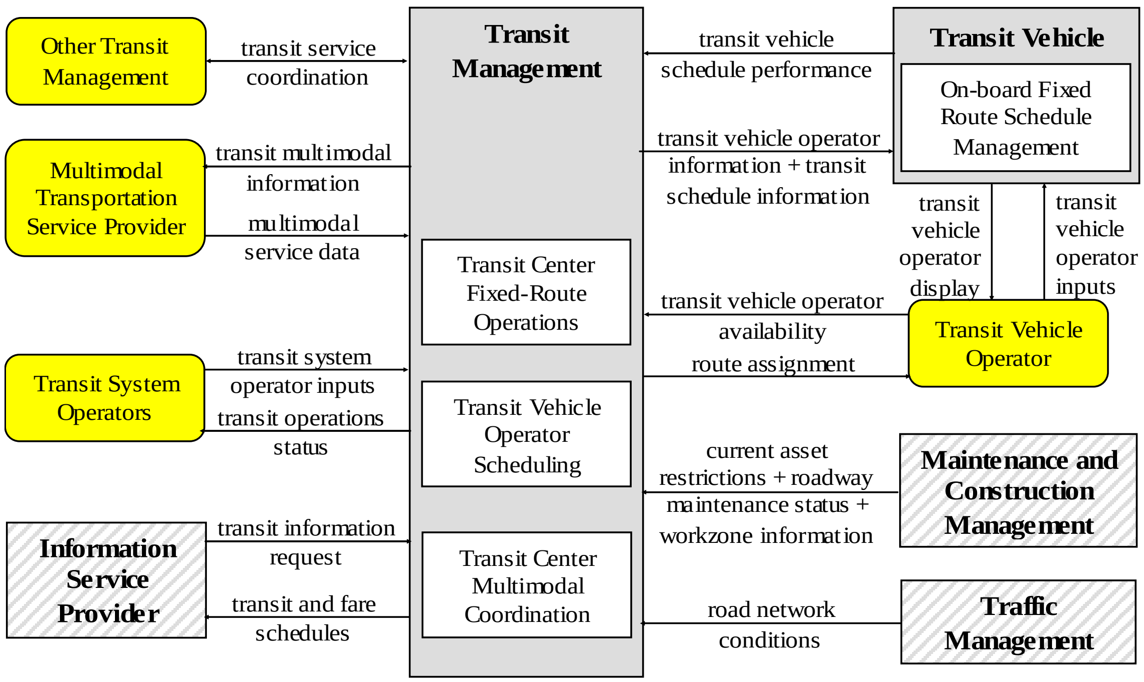
Feature diagram for “(2.3) – “Precision Docking”



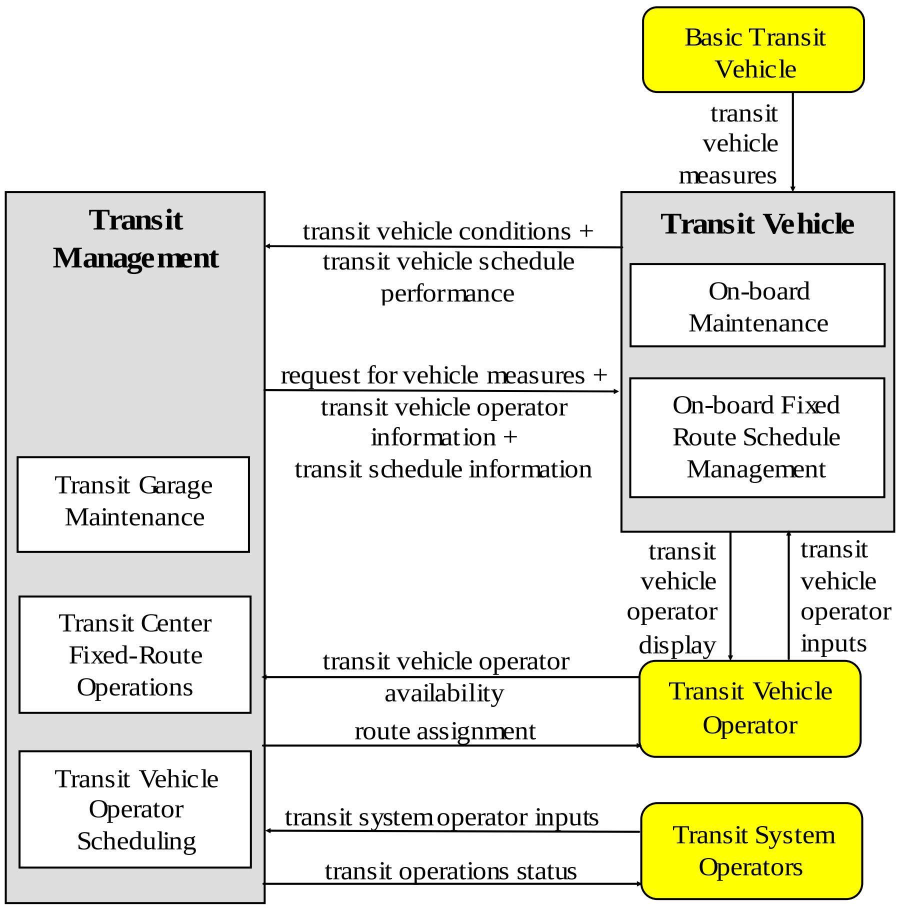
Feature diagram for "(2.4) – "Vehicle Guidance (Lane Assist)"



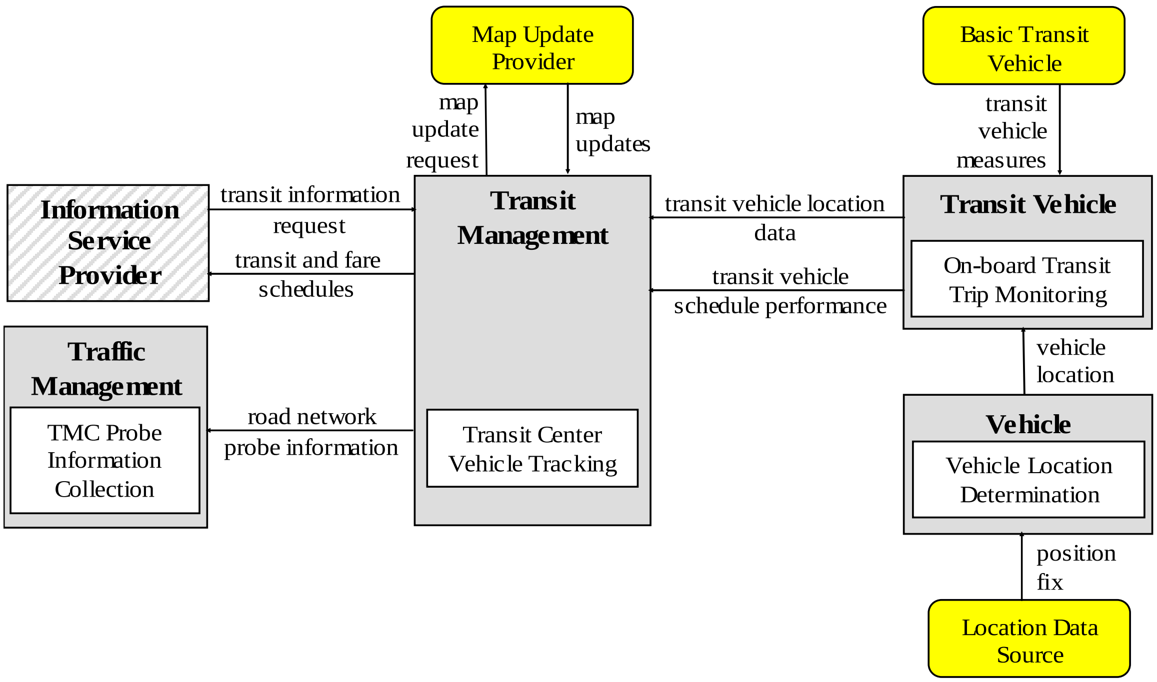
Feature diagram for "(3.1) – "Automated Scheduling Dispatch System (with Connection Protection"



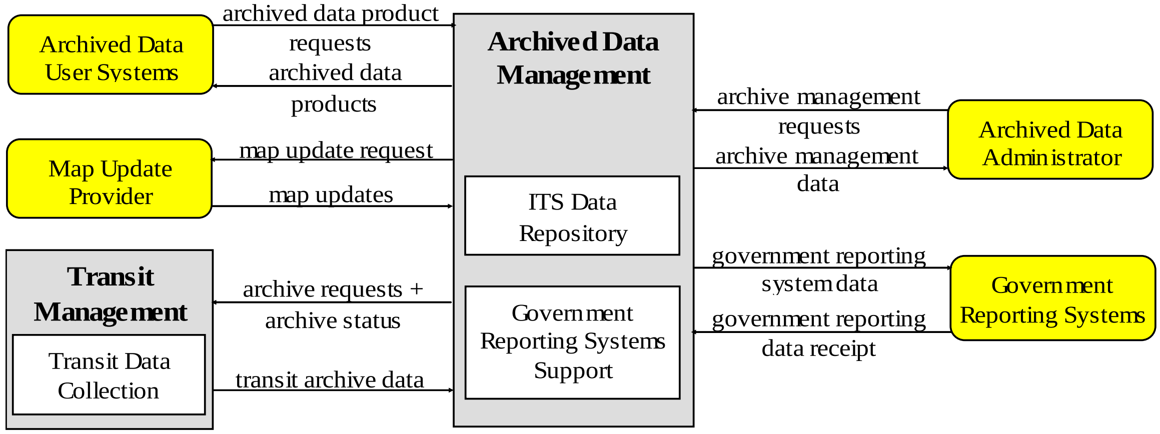
Feature diagram for "(3.2) – "Vehicle Mechanical Monitoring and Maintenance"



Feature diagram for "(3.3) – "Vehicle Tracking (with Buses as Traffic Probes)"

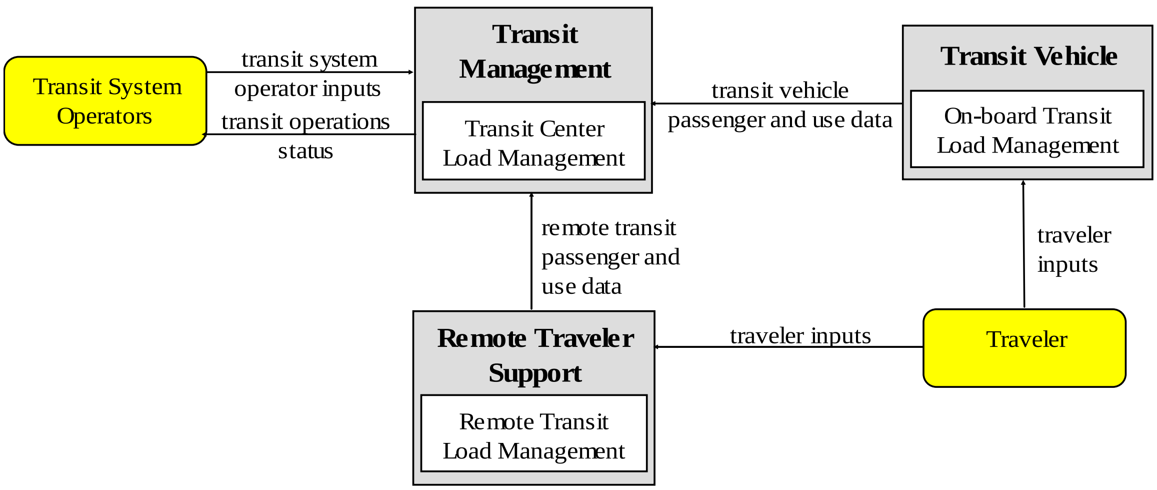


Feature diagram for "(3.4) – "Archived Data"

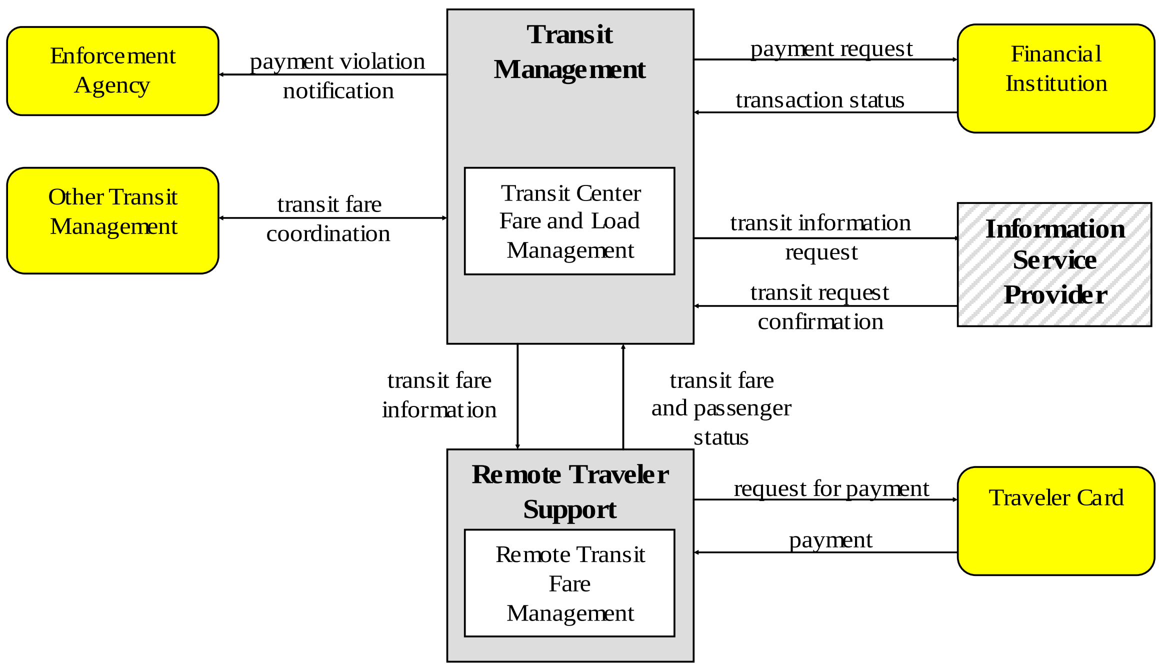


Feature diagram for "(3.5) – "Passenger Counting"

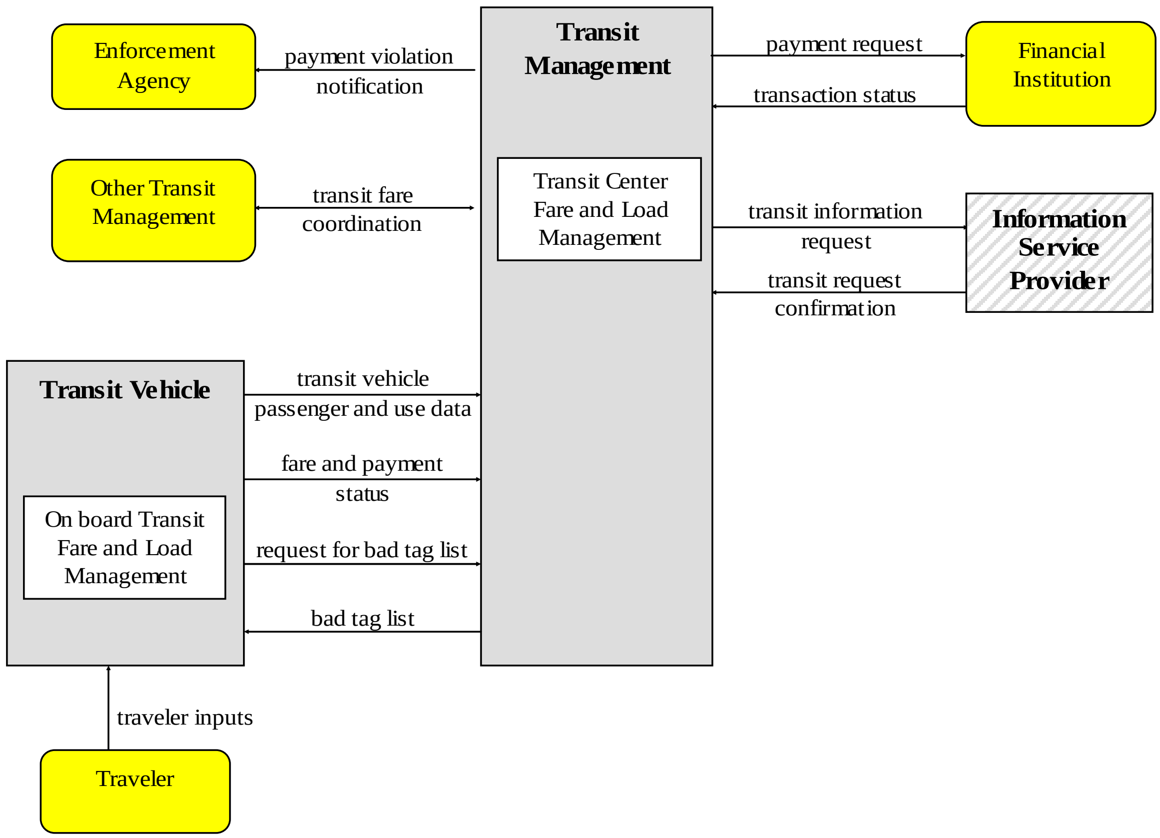
In this feature diagram, the specific task of passenger counting and load management has been identified. Additional entities, flows, and equipment packages would be added **if** passenger counting is included with fare payment.



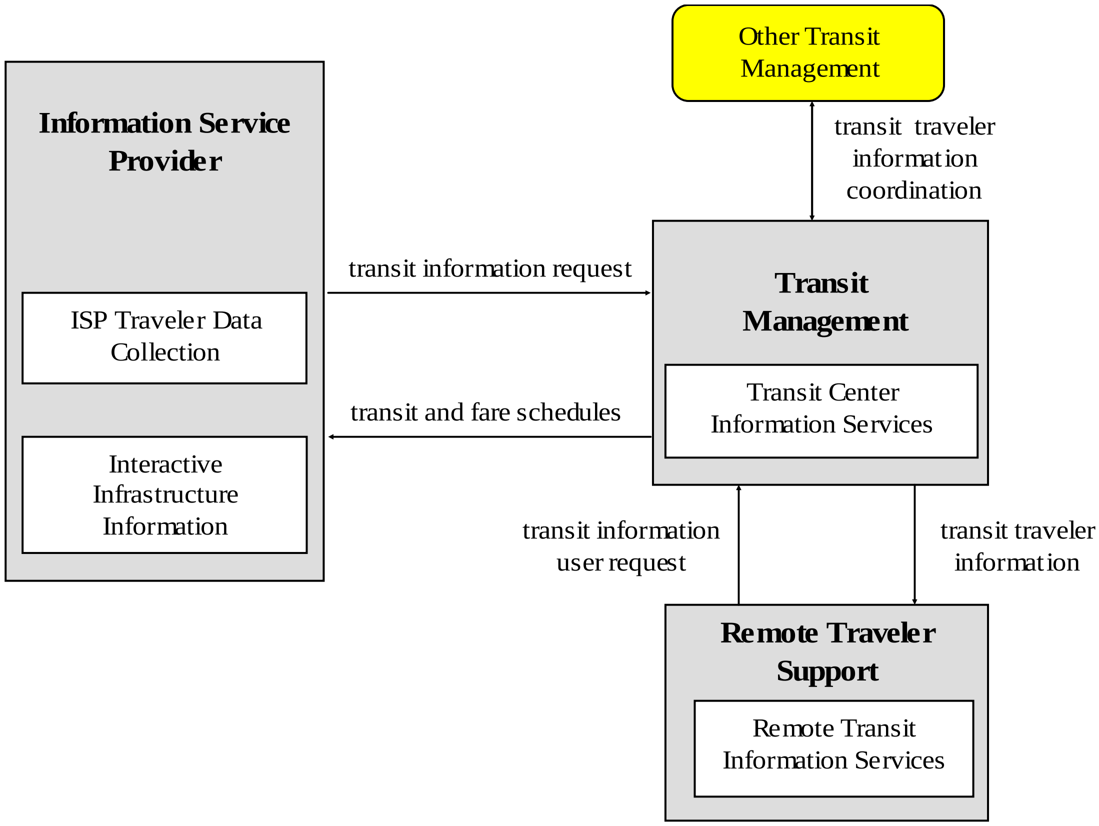
Feature diagram for "(4.1) – "Station-based Electronic Fare Payment"



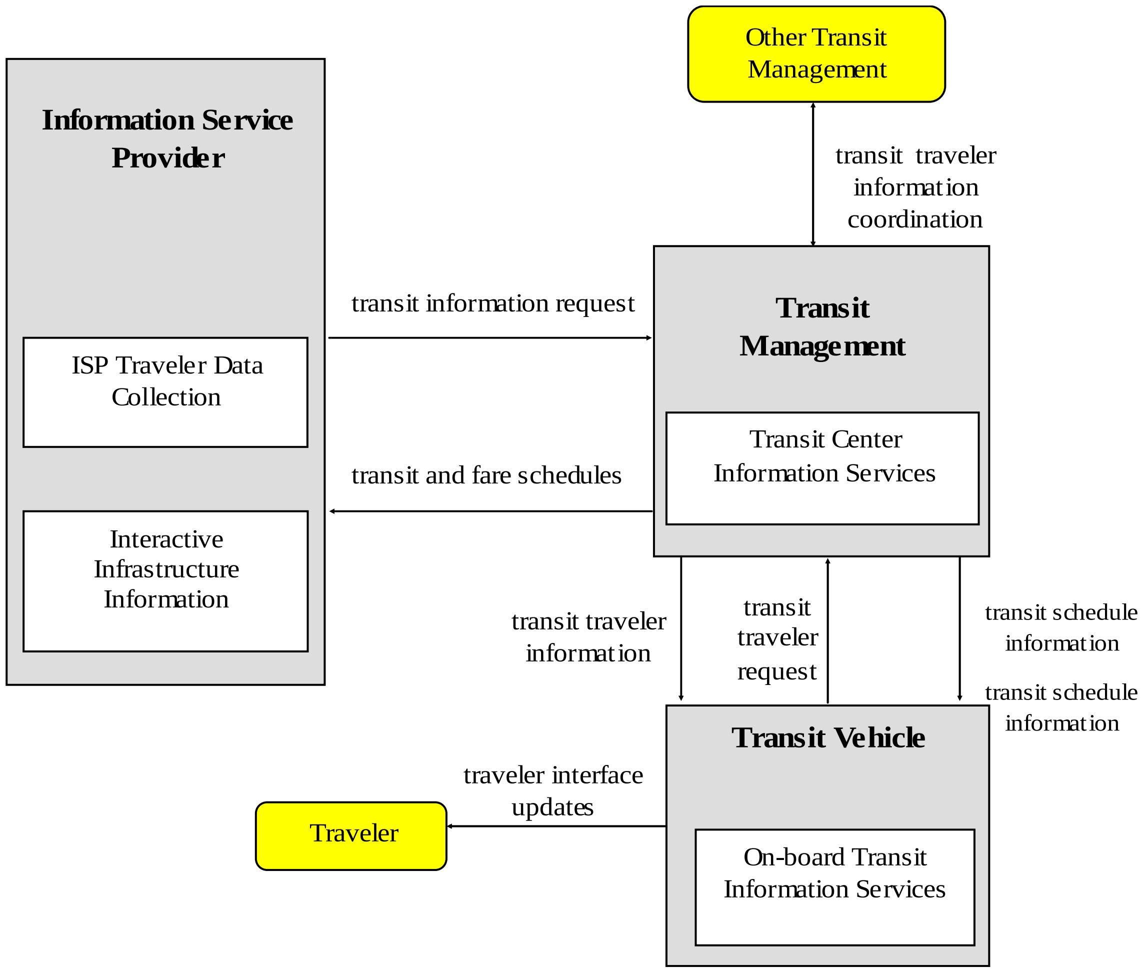
Feature diagram for "(4.2) – "Vehicle-based Electronic Fare Payment"



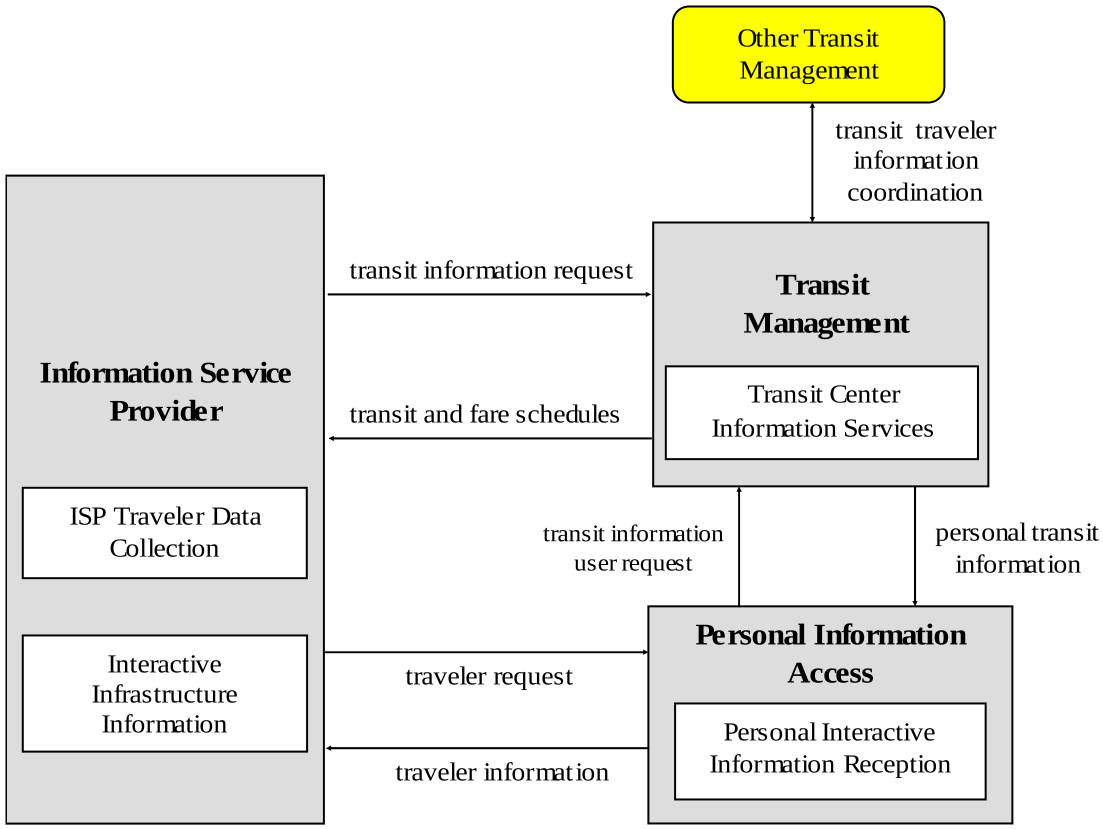
Feature diagram for “(5.1) – “Traveler Information at Stations/Stops”



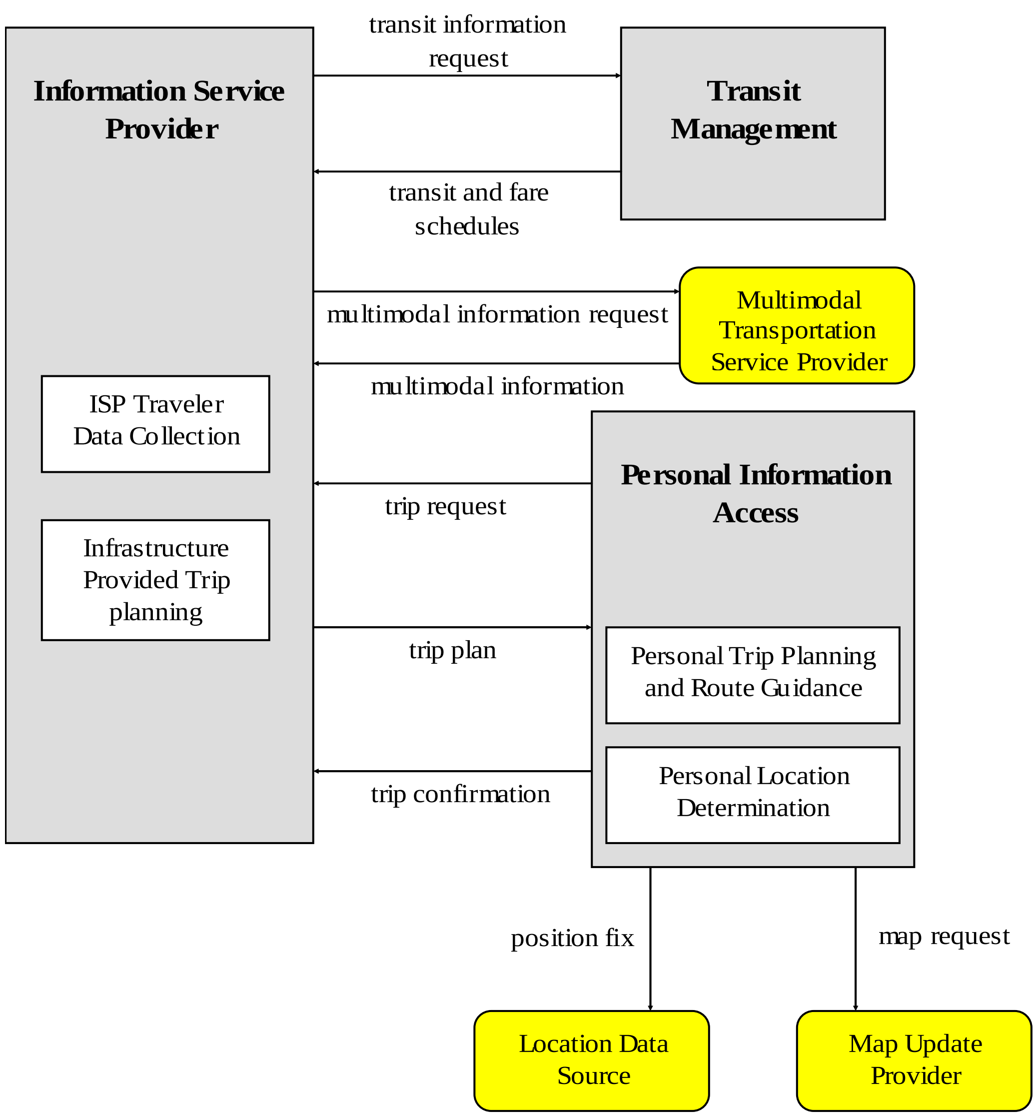
Feature diagram for “(5.2) – “Traveler Information in Vehicles”



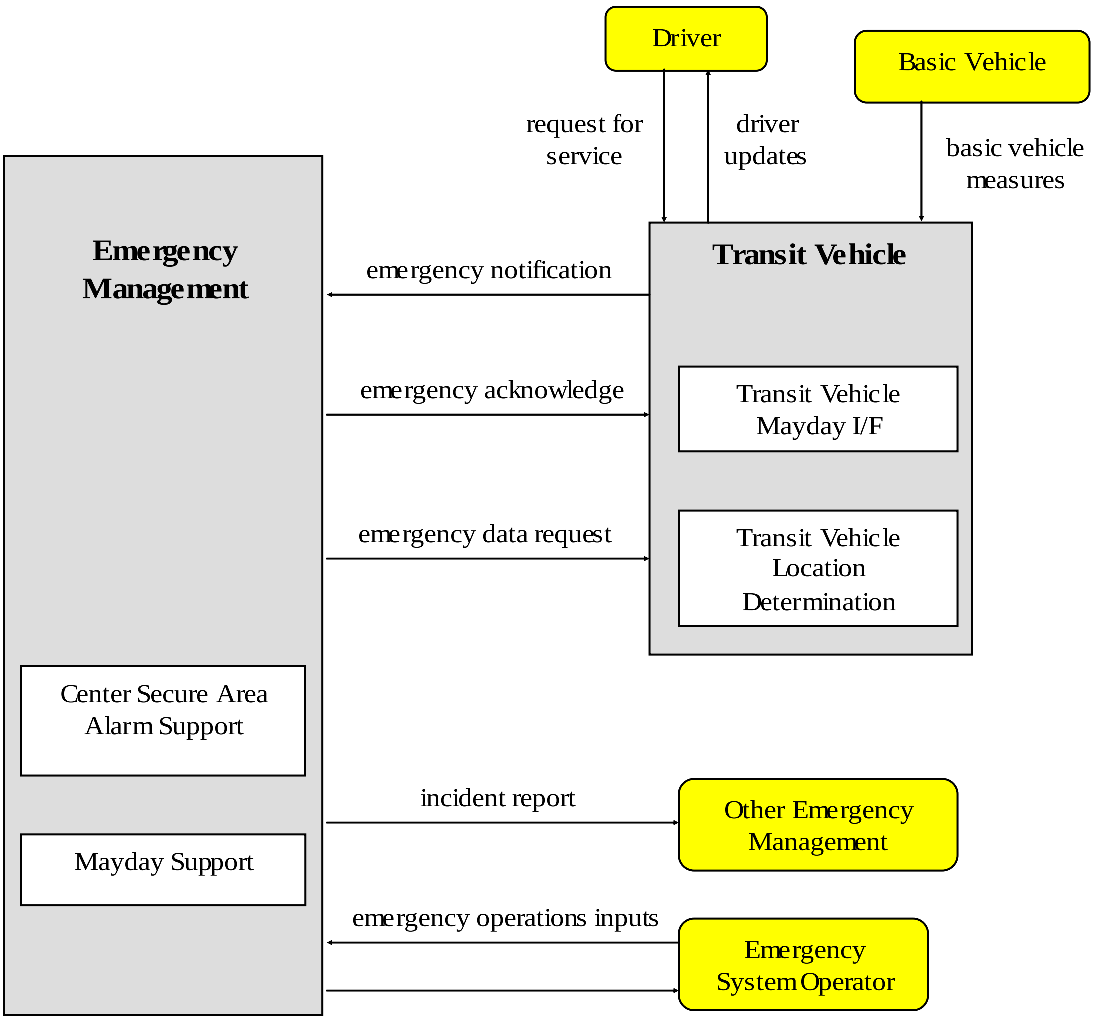
Feature diagram for "(5.3) – "Traveler Information on Person"



Feature diagram for "(5.4) – "Pre-Trip Itinerary Planning"



Feature diagram for "(6.1) – "Silent Alarm"



Feature diagram for “(6.2) – “Voice and Video Monitoring”