Title

Development of Deployment Strategy for an Integrated BRT System

Authors
Miller, Mark A.
Tan, Chin-Woo
Golub, Aaron
et al.

Publication Date
2006-05-18

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

Development of Deployment Strategy for an Integrated BRT System

Mark A, Miller, Chin-Woo Tan, Aaron Golub, Mark Hickman, Peter Lau, Wei-Bin Zhang

California PATH Research Report
UCB-ITS-PRR-2006-9

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.

Final Report for Task Order 4408, 5603

May 2006

ISSN 1055-1425

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

Development of Deployment Strategy for an Integrated BRT System

Mark A. Miller
Chin-Woo Tan
Aaron Golub
Mark Hickman
Peter Lau
Wei-Bin Zhang

Final Report for Contract Number 65A0161─Task Orders 5603 and 4408

May 18, 2006

ACKNOWLEDGEMENTS

This work was performed by the California PATH Program at the University of California at Berkeley under sponsorship of the State of California Business, Transportation and Housing Agency, Department of Transportation (Caltrans), Division of Research and Innovation (DR&I) (Interagency Agreement #65A0161). The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California.

The authors acknowledge and thank Sonja Sun and Don Dean of DR&I for their support of this project. The authors also thank Steven Shladover of the PATH Program and Yafeng Yin formerly of the PATH Program for their valuable support of and contributions to this project. Finally, the authors thank Tunde Balvanyos, formerly of the PATH Program, for her support of this project.

ABSTRACT

BRT mixes the flexibility of traditional bus transit service with an array of higher performance rail transit features. One of its advantages over rail, however, is its possibility for incremental and flexible deployment. With this flexibility and incremental nature comes a deployment process for BRT that is highly complex because numerous elements can be incorporated in any number of distinct phases. In almost all BRT deployments, ITS and advanced bus technologies have been applied to BRT, however, in less than a fully integrated manner. This project explores how deployment decisions can be made easier, perhaps more rational, and in a more integrated fashion by clarifying the relationships between different BRT elements, and how the different planning-level goals of deployment are affected by decisions regarding particular elements. Both a system architecture and a prototype visual tool have been developed, showing the relationships between and among common BRT elements and major decision areas.

Key Words: bus rapid transit, planning, integration, deployment phasing, architecture

EXECUTIVE SUMMARY

This report constitutes the final deliverable for PATH Project Task Orders 5603 and 4408 under contract 65A0161 — "Development of Deployment Strategy for an Integrated Bus Rapid Transit System".

Bus Rapid Transit systems can combine the flexibility of buses with the higher performance characteristics of fixed guideway (rail) operations. Unlike rail systems, however, because buses are self-guided and can operate over any right of way with sufficient width, BRT systems need not achieve a certain stage of development before operations can begin. BRT can be considered to be "treatment" of a traditional bus corridor, with any number of a wide variety of "elements" including: infrastructure and rights of way enhancements, segregation of parts or all of the rights of way, new vehicle types, automated vehicle guidance systems, improved stops and shelters, enhanced traveler information on-board and at transit stops, and new product identification and marketing approaches. Many practitioners would agree, however, that BRT must include a minimum level of improvements to legitimately be named as such, including a significant decrease in travel times in the corridor, and significant new branding and marketing for the route.

Many BRT corridors are typically deployed beginning with an "enhanced" treatment of urban buses operating in mixed traffic, and proceeding to a more complete approach with some segregation, signal priority and other ITS and traveler information applications. This project seeks to assist the transit community with tools to understand and optimize this deployment process of the BRT elements over time. In developing the deployment strategy for a BRT corridor, transit agencies must consider 1) into how many phases should the deployment process be divided, 2) when these deployment phases should occur, and 3) which elements should be deployed at which phase under the constraints such as the budget for each phase as well as elements that are pre-determined by the agency (or other stakeholders) to occur in each phase.

Within these constraints there is considerable room for improving the deployment process and the benefits derived from the project over its service life. Savings may be made by coordinating parts of the deployment, and likewise, greater benefits can be made by the synergy between certain groups of elements.

Bus Rapid Transit systems may be deployed, that is, can begin operation as soon as new operational and marketing plans are developed. That is, as a first step, existing buses and stops can be used in conjunction with a new regime of service, which will approximate the future BRT system. From there, elements can be added: new shelters, new buses, new traveler information systems, and new segregated rights of way. And this can happen over any number of phases. However, it must also be recognized that a systems approach needs to be taken with regard to the deployment decision in the sense of a through a more holistic discussion of combinations of BRT elements.

We began our investigation into the deployment phasing nature of bus rapid transit by reviewing — from the deployment perspective — numerous bus rapid transit systems from both within the United States and outside to ascertain information regarding the incremental nature and phasing aspects of their implementation. A primary lesson learned from this review was that the deployment process for BRT is highly complex because numerous elements can be incorporated in any number of distinct phases at multiple times. In almost all BRT deployments, intelligent transportation systems (ITS) and advanced bus technologies have been applied to BRT, however, in less than a fully integrated manner.

Our project objective was to develop a more integrated approach in the application of ITS as well as other technologies toward the deployment of bus rapid transit systems. This project explores how deployment decisions can be made easier and perhaps more rational by clarifying the relationships between the different BRT elements, and how the different planning-level goals of deployment are affected by decisions regarding particular elements.

A prototype visual tool was developed, showing the relationships between twenty common BRT elements and seven major decision areas. The goals of the tool are to assist transit agency staff by clarifying the implications of deployment phasing and deploying particular combinations of elements. It is proposed that the tool can be operationalized as a "front-end" to more detailed planning-level modeling information involving the costs and benefits of candidate deployment decisions and element combinations.

A bus rapid transit system architecture has also been developed. 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 may be initiated by associating the application needs with each of the system functions and translating these requirements into the subsystem-level requirements. The BRT architecture was modeled after the National ITS architecture for compatibility purposes. 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 created a physical architecture modeled around each of the BRT features. The physical layer of BRT architecture was developed to define BRT with a physical representation of how the system should provide the required functionality. In the final step, the logical architecture was mapped from the physical architecture in such a way that the physical layer implemented the processes identified in the logical architecture and assigned them to subsystems, and the data flows that originate from one subsystem and end at another are grouped together into architecture flows with defined interface requirements.

The proposed methodology can contribute to the expansion of the National ITS Architecture to include 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 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. The analysis will provide an important launching point for continued development of BRT architecture.

LIST OF TABLES **PAGE**

LIST OF FIGURES — PAGE

LIST OF FIGURES **PAGE**

TABLE OF CONTENTS

SECTION		PAGE

SECTION		PAGE

1.0 INTRODUCTION

This report constitutes part of the Final Deliverable for PATH Project Task Orders 5603 and 4408 under contract 65A0161 — "Development of Deployment Strategy for an Integrated Bus Rapid Transit System".

The transit industry nationwide has developed significant interest in bus rapid transit (BRT) systems. Recent deployments of BRT systems have demonstrated that such systems can deliver similar levels of service as rail transit and offer significant advantages over the traditional rail system. For example, BRT has the flexibility that can be integrated with current urban settings and can be deployed progressively. Recent studies have shown that a BRT system that can achieve comparable rail service level costs less than one-half of the rail system.

As BRT may involve new operations, design approaches and technologies, integrated planning and deployment strategies are needed for this new mode of transportation system. However, most of the current BRT deployment enterprises in the United States are often lacking an integrated approach to planning and implementation. As a result, the BRT systems that are currently in planning or are being deployed may not be most cost effective for realizing their full potential in terms of benefits to the bus transit passengers and the transit property.

Currently there are over 200 transit properties in the United States that are considering BRT alternatives and a few dozen are conducting planning exercises to evaluate the viability of BRT for their agency. Under the federal guidelines for New Start Programs, such planning studies go through a number of major steps, including Major Investment Studies (MIS) or Alternatives Analysis, Preliminary Engineering and Final Engineering Designs.

In most cases, the Alternatives Analysis is critical to the locals and the federal government to decide if BRT is the most cost effective means to provide transit options. During the Alternatives Analysis, the definitions of the alternatives are continually refined as various strategies, system design options, and project elements are tested. The result is a Final Definition of Alternatives and technical planning information about each alternative. The main indicator that confirms a properly defined set of alternatives is the cost effectiveness of the Build vs. No-build, and system modification vs. the No-build. Cost effectiveness is normally defined as either cost per new trip or as cost per hour of user benefits.

As transit authorities are interested in BRT alternatives, consulting firms begin to enter into the arena of BRT planning studies and engineering designs. Many of them have no proper training in BRT and are using either rail systems or traditional transit as models to study BRT. There is no doubt that, similar to any transportation system improvement projects, the cost effectiveness of each option is very location and application dependent. However, BRT has different characteristics as compared with traditional rail and transit systems. It is critical that the definitions of alternatives, deployment strategies, system-design options and project elements are chosen following standard guidelines and practices that reflect the characteristics of BRT. There is therefore a necessity to develop guidelines and best practices in order to support planning a cost effective BRT system. There is also a necessity for a system engineering approach to conduct engineering design of the BRT system in order to achieve a fully integrated BRT deployment.

1.1 Motivation and Objectives

BRT is different from traditional bus transit service by incorporating many rail transit features. It also differs from traditional rail with its flexibility and the possibility for incremental deployment. In deployment planning for BRT, one of the major issues is to determine how the deployment of a BRT system will be phased in over time. Currently, there is no rigorous way to do it. When and which BRT element should be implemented is a tradeoff between the costs associated with it, its ease of implementation (physical constraints and institutional issues) and resultant benefits for the specific application site. Another issue identified is the issue of integrated deployment of advanced technologies. In almost all BRT deployments, ITS and other bus technologies have been applied to BRT, however, in less than a fully integrated manner. For example, the current bus data communication system has not yet considered many BRT features, therefore many of the add-on functions and features cannot be integrated with the current bus system. As another example, a transit bus that is instrumented with advanced communication systems (ACS), signal priority systems, and bus arrival information functions is often equipped with three separate positioning systems. There are also plenty of examples that data collected by the advanced location and communication systems were archived but not used by many agencies. This non-integrated approach to add-on technologies creates several issues, in particular:

- It inevitably increases the cost of the BRT system to the extent that transit agencies are often forced to make a careful selection of the technologies that offer greater benefits, even though other technologies may also provide substantial benefit.
- The non-integrated systems become unnecessarily complicated, which not only creates significant maintenance hassles but also significantly reduces the reliability of the overall system.
- The applications' various ITS technologies are not integrated. Specifically, data collected from one system often cannot be used by the other systems and few application tools are available to take advantage of the significant amount of data collected by new technologies.

Therefore, integrated deployment of ITS technologies is urgently needed for transit applications, particularly for BRT. The goal of the proposed study is to develop cost-effective planning and deployment strategies for integrated bus rapid transit systems. The study has two objectives: (1) to develop a systematic methodology for deployment phasing planning and (2) to develop implementation concepts for integrating BRT technologies.

1.2 Contents of the Report

This is the first of three sections. Section 2 presents the findings of our research in developing a methodology for planning of phased deployment of bus rapid transit systems. Section 3 describes the research performed using a systems engineering approach to develop an architecture — with both logical and physical elements — for bus rapid transit.

2.0 DEVELOPMENT OF SYSTEMATIC METHODOLOGY FOR DEPLOYMENT PHASING PLANNING

2.1 Background Information

This chapter's primary objective is to develop a systematic methodology for deployment phasing planning. In the remainder of this report we use the following definition of bus rapid transit developed as part of the recently completed Transit Cooperative Research Project A-23 (1). Bus rapid transit (BRT) is defined as a

> "Flexible, rubber-tired rapid-transit mode that combines stations, vehicles, services, running ways, and intelligent transportation system elements into an integrated system with a strong positive identity that evokes a unique image. BRT applications are designed to be appropriate to the market they serve and their physical surroundings, and they can be incrementally implemented in a variety of environments."

2.2 Planning For Bus Rapid Transit Systems

The decision by a transit agency to consider investing in bus rapid transit should mean that it follows the same basic planning and project planning process as one might use for any rapid transit investment, irrespective of whether requesting Federal-funding assistance is being contemplated. Having enunciated and gotten policy official endorsement of goals, objectives and criteria, transportation planners will begin the rapid transit planning and project development process (i.e., "New Start planning and project development process) with an in-depth analysis of the characteristics and causes of current and potential future transportation and transportation related problems in a given corridor. This corridor (or corridors) will have been identified by the ongoing systems planning process as needing a rapid transit investment of some kind. This analysis, known as an "alternatives analysis" will focus on multi-modal (transit and highway) demand, supply condition and performance in the corridor or corridors in question. It will also cover transportation-related environmental, social, economic development and land use related challenges and issues (Figure 1).

After a complete analysis of the current and projected future (i.e. analysis of a no project or "do-nothing" alternative) situation, alternative rapid transit and/or multi-modal solutions can be identified. The first alternatives(s) to be identified will be one or more modest investment alternatives also referred to as "TSM" or base-case alternatives. These will include both additions of new capacity and services as well as operational improvements.

Based on the results of analysis of the "TSM" alternatives, one or more rapid transit alternatives are identified and analyzed. Where a modest BRT investment is being contemplated, there may be only one rapid transit "build" alternative, while where a more expensive (e.g., in excess of $75m) BRT and other rail-based alternatives are being examined, less expensive rapid transit alternatives will be examined as well.

Following the open, objective analysis of the full range of alternatives in terms of the goals, objectives and criteria enunciated at the beginning of the planning process, policy officials will select the single rapid transit alternative to take into more detailed planning, engineering and design (Figure 2). This alternative will be defined in terms of basic mode, and general alignment. The next step in the process, preliminary engineering, further defines the alternative selected at the conclusion of alternatives analysis to a level of detail normally requiring completion of 30% of all engineering and design activities.

At the conclusion of preliminary engineering, the environmental review process under the National Environmental Policy Act (NEPA) will have been completed. At this point the scope and cost of the project will be known with a level of confidence permitting commitment to construction of the project by the various funding partners, including the Federal Transit Administration. The Federal commitment will reflect a rigorous cost-effectiveness analysis utilizing the results of both the alternatives analysis and preliminary engineering processes.

The recently enacted Federal Surface Transportation legislation: "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users" (SAFETEA-LU) requires a less-rigorous alternatives analysis and FTA evaluation process for project where less than $75m of Federal funds are being requested, under a new "Small Start" transit capital assistance program; however, the basic process described above and illustrated below will be the same as for major "New Start" projects.

FIGURE 1 Schematic Diagram of Alternatives Analysis Process

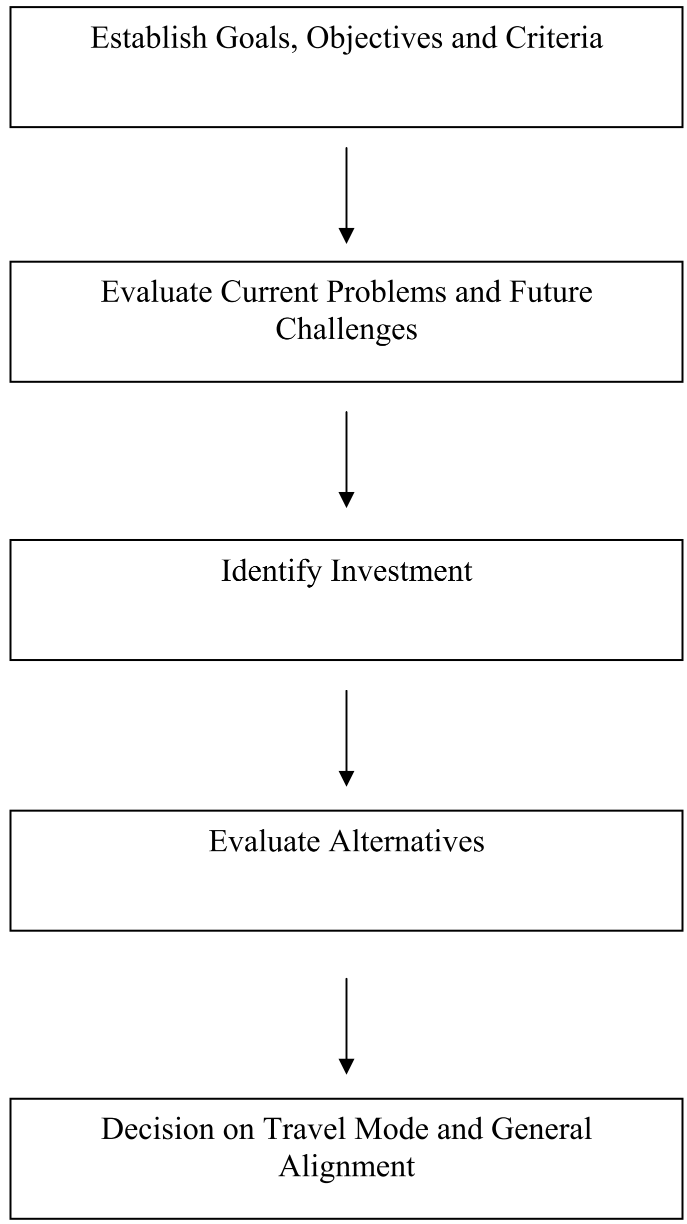
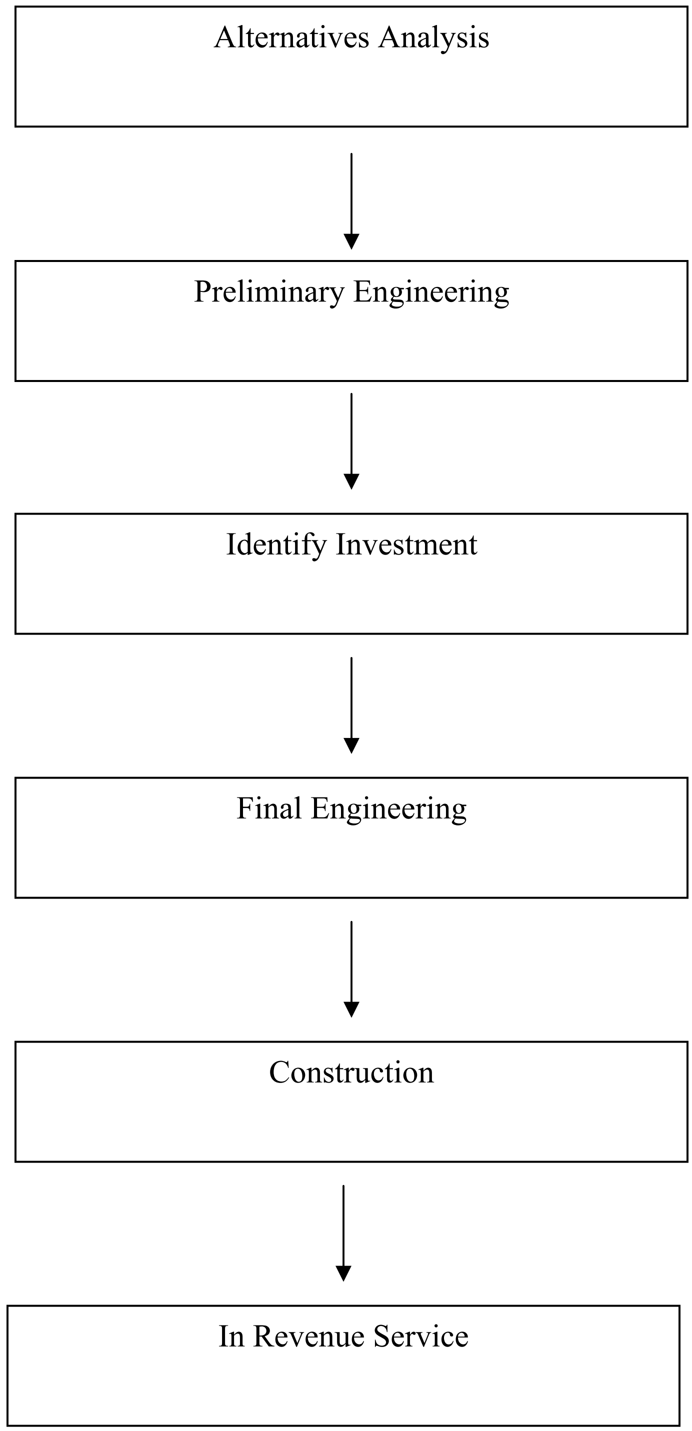


FIGURE 2 Alternatives Analysis In The Over-All Planning And Project Development Continuum



However, due to its inherently flexible nature that permits incremental deployment phasing over time — a unique characteristic of BRT — bus rapid transit can undergo additional planning scrutiny to determine what BRT elements will be included and their deployment sequencing in phases/stages over time. Of course, after the Alternatives Analysis portion of the Project Development Process, a parallel operations planning process usually gets underway that includes designing routes and stations, setting timetables, scheduling vehicles, and assigning crews.

2.3 Impact of BRT Element Combinations on System Performance

It is perhaps fair to say that no two Bus Rapid Transit (BRT) systems in operation around world are identical. The one common feature; however, is that each system comprises a series of basic elements. The difference in each system being the choice of option for each element, with some options being far more advanced than others. These elements also form the basic structure of any rapid transit service, including light rail or commuter rail. The major advantage of Bus Rapid Transit over fixed-guideway forms of transit is its flexibility and ability to be implemented in almost any operating environment, as well as tailored to suit all budgets. The elements that comprise any rapid transit system are 1) running ways, 2) stations, 3) vehicles, 4) intelligent transportation systems, 5) fare collection, and 6) service and operations plan. Each of these six primary elements may be further disaggregated into separate sub-elements (2).

- *Running Ways* — By virtue of BRT vehicles being rubber tired and steered (as well as guided in some cases), BRT services can operate in a variety of physical environments, ranging from mixed traffic to dedicated curbside or offset lanes, median arterial busways and bus-only transitways that may be at the surface, elevated or in tunnels. Most corridor applications utilize a combination of the above due to neighborhood and street/highway system conditions and constraints. In summary, we may categorize running ways according to their
    - <u>Segregation</u> — Examples include 1) mixed flow lanes with queue jumpers, 2) dedicated (reserved) arterial lanes, 3) at-grade exclusive transitways, and 4) grade-separated exclusive transitways. Queue jumpers allow vehicles to bypass traffic queues at signalized locations and bottlenecks. Dedicated arterial lanes reduce delays associated with congestion in urban areas. At-grade exclusive transitways can remove hazards due to merging or turning traffic, pedestrians, or bicyclists crossing in the interior of the running way, allowing BRT vehicles to travel more safely at higher speeds.
    - <u>Guidance</u> — Guidance technologies integrated into the running way/vehicle interface allow vehicles to follow a specified path along the running way and in approaches to stations and thus travel safely while maintaining close lateral tolerances.
    - <u>Differentiation/Markings</u> — These can supplement brand identity and advertise the BRT system by providing it with a distinct image and make enforcement easier when there is not a physical barrier that separates the BRT-only running ways from general traffic. Examples include “Bus Only” or “BRT Only” pavement markings, use of different colors on the BRT running way.

- *Stations* — Stations commonly used for BRT schemes vary from system to system; however, they are generally of a more advanced nature that those typically used on bus transit routes. They can combine state of the art passenger information technology, with the comfort and convenience of rail stations, along with improved safety and fare collection systems. The planning and design of stations is a combination of factors (station spacing and design feature, platform location and length) all of which have an important role in the overall success of the scheme. In summary, we may categorize stations according to their

- Station Design — Since passengers can potentially spend time at stations in an exposed environment, designing stations to minimize exposure to crime or security threats is important.
- Station Type — The design of transfer stations can facilitate lower transfer times, walking distances, and fewer level changes.
- Platform Height — Level platforms help to reduce the "gap" between the BRT vehicle floor and station platform edge, which in turn can help speed the boarding and alighting process.
- Platform Layout — Platform layouts that do not constrain the number of vehicles that can load and unload passengers, help reduce the amount of time vehicles spend at stations waiting in vehicle queues.
- Passing Capability — Such stations that allow for passing can reduce delays at stations and also allows for the service plan to incorporate route options such as skip-stop or express routes that offer lower travel times than routes that serve all stations.

- *Vehicles* — Standard diesel buses, both 40 foot and 60 foot are widely used for BRT operations. There is however a trend toward innovations in vehicle design in terms of (1) "clean" propulsion systems (e.g., diesels with self regenerating after-burners using low sulfur diesel fuel; diesel/CNG/gasoline - electric hybrids; compressed natural gas [CNG] fueled spark ignition engines) (2) dual-mode (diesel-electric) vehicles that permit on-wire operation through tunnels, regular diesel operation elsewhere; (3) 100% low-floor buses with inordinately wide stairwells; (4) buses with more and wider doors; and (5) use of distinctive BRT vehicles with unique styling and operational features such as the ability to dock close enough to station platform edges to permit level, no-step boarding and alighting. We may group vehicles according to their
  - Vehicle Configuration — BRT vehicles with low floors facilitate boarding and alighting, especially for mobility impaired individuals.
  - Passenger Circulation Enhancement — All types of improving passenger circulation, such as through additional door channels, alternative seating layouts, or enhanced wheelchair securements, can reduce dwell times.
  - Aesthetic Enhancements — Use of large windows can reinforce brand messages of being "open" and "safe" and low floor buses with their generally high ceilings help provide the passenger with a feeling of spaciousness, which contributes to their overall comfort.
  - Propulsion — Clean/alternative propulsion systems and fuels have positive effects on community integration as well as service image and branding. Concern for air pollution and community health effects associated with conventional diesel buses are important as is their noise.

- *Intelligent Transportation Systems (ITS)* — Applications of ITS technologies in BRT systems begin with those that are operations-oriented such as 1) fleet management, including automatic vehicle location (AVL) systems, automatic passenger counters, and surveillance systems through the use of remote sensing and close circuit TV, and 2) electronic fare payment systems and passenger-oriented, namely passenger information systems either on-board the bus or at stations/stops. AVL systems automatically determine and track the real-time geospatial location of a bus. Several different technologies may be used to perform AVL, such as GPS, ground-based radio, signpost and odometer, dead reckoning, and combinations of these. Automatic passenger counters are devices that count passengers automatically as they board and alight transit vehicles, typically buses. Most common technologies include treadle mats or infrared beams. Electronic fare payment systems provide an electronic means of collecting and processing fares. Passengers can use a magnetic stripe card, smart card, or credit card instead of tokens or cash to pay for transit trips. Smart cards have the ability to store monetary value and other information on an embedded integrated circuit or microchip. There are several additional technological systems that may be involved in the implementation of bus rapid transit systems and are at different stages of research, development, and deployment. They include collision warning systems, transit signal priority systems, and vehicle assist and automation systems such as precision docking, automatic steering control systems, and automatic speed and spacing control systems. We may group ITS into the following groupings:
    - <u>Transit Signal Prioritization</u> — Transit signal priority systems makes it possible for a bus approaching an intersection during the final seconds of the green signal cycle to be detected and to request an extension of the green cycle so that the bus can pass through before the signal turns red, thereby saving the bus and its passengers the red cycle time. This tends to provide additional time saving benefits to the other vehicles traveling in the same direction as the bus, while increasing the time delays to the crossing traffic. TSP allows a BRT vehicle to maintain its schedule by giving those BRT vehicles that are behind schedule extra green time.
    - <u>Driver Assist and Automation</u> — Lane assist systems can allow the BRT vehicle operator to travel at higher speeds than otherwise would be possible due to the physical constraints of the right-of-way. Precision docking enables a BRT vehicle to come to a complete stop at a BRT stop/station quicker than otherwise could be accomplished thus reducing running travel time and station dwell time.
    - <u>Operations Management</u> — Particular operations management technologies such as automated scheduling and dispatch systems and automatic vehicle location systems can help insure more even headways and thus reduced wait times.
    - <u>Passenger Information Systems</u> — Real-time passenger information systems do not directly impact wait time; however, by providing up-to-date and accurate information on BRT vehicle arrival times, such systems do permit passengers to change their wait time expectations, level of anxiety and stress, and thus help reduce the burden that passengers associate with waiting for their bus.
    - <u>Safety and Security Technologies</u> — BRT security may be addressed by using operations management technologies such as automated scheduling and dispatch

and vehicle tracking systems. Moreover, silent alarms and voice and video monitoring are important to the security of the BRT vehicle and passengers.

- *Fare Collection* — Several alternative fare collection systems exist, from the relatively low-tech using exact change to highly advance smartcard technologies. The three primary attributes of a fare collection system consist of the fare collection process, fare media, and Smart Cards. There are four basic forms of fare payment systems utilized in transit networks, including on-board payment, conductor validated payment, barrier enforced payment, and proof of payment systems. The fare structure is also an important consideration under this element and can consist of flat fares or differentiated fares. We may group Fare Collection into the following two groupings:
    - <u>Fare Collection Process</u> — Fare collection processes, such as proof-of-payment and barrier-enforced pre-payment, that allow multiple door boarding can provide reductions in boarding times and hence reduce overall dwell times.
    - <u>Fare Transaction Media</u> — For options where fare transactions occur inside the vehicle, the fare transaction media will increase station dwell time compared to fare transaction options that take place before entering the vehicle. There are also differences among transaction media all of whom occur in the vehicle, such as cash payment, Smart Card, Magnetic Stripe Card.

- *Service and Operations Plan* — BRT service patterns, based on the nature of the given corridor's transit market, determine the types of running way and vehicles utilized. Many systems provide an "overlay" of peak-only express or limited stop services on top of an all-day, all-stops local route. They also utilize "feeder" bus lines intersecting BRT routes at selected stations. Services on most systems extend beyond the limits of transitways or dedicated bus lanes – an important advantage of BRT. However, because of door arrangements, platform heights and/or propulsion systems, BRT systems in Jakarta, Bogotá, Curitiba, and Quito operate only within the limits of the special running ways. Some systems (e.g., Ottawa, Brisbane, Pittsburgh and Miami) feature line haul routes operating on transit ways that are integrated with off-line, off-transitway feeders at the trip production (home) end and distributors at the attraction or non-home end. BRT operating headways should be less than 10 minutes where feasible and should be in operation all-day to minimize potential confusion for riders. We may group Service and Operations Plan into the following groupings:
    - <u>Station Spacing</u> — Reduces the number of stations reduces delay associated with decelerating into and accelerating out of stations and with station loading.
    - <u>Method of Schedule Control</u> — When frequencies are sufficiently large, encouraging vehicle operators to travel the corridor as fast as possible within the legal speed limit and managing on-time performance through headway-based schedule control can encourage vehicles to travel at the maximum speeds that are possible between stations.
    - <u>Service Frequency</u> — Service frequency is the key determinant of waiting and transfer times. Moreover, increasing service frequency reduces the number of passengers that can accumulate at a single station, reducing the time associated with loading them.

- Route Structure — BRT route structures bringing together multiple routes that converge into a common trunk can increase the number and types of services available to transit passengers at high volume stations. Moreover, multiple routes traveling the same corridor increase the frequency along the corridor and reduce the amount of time waiting for BRT service.
- Route Length — Running time reliability is more possible with shorter route lengths.
- Service Span — Service that extends to the off-peak periods of the day and on weekends provides potential users with expanded options for making round trips. Expanded service spans help make BRT systems more dependable.

System performance for BRT systems is assessed according to five key measures – travel time, reliability, identity and image, safety and security, and system capacity. Each BRT system element has different effects on system performance. These five measures may be further disaggregated as follows:

Travel Time
- Running Time
- Station Dwell Time
- Waiting and Transfer Time

Reliability
- Running time reliability
- Station time reliability
- Service reliability

Image and Identity
- Brand Identity
- Contextual design

Safety and Security
- Safety
- Security

Capacity
- Person capacity

Overview summaries of which bus rapid transit system elements and sub-elements affect which system performance component are depicted in Tables 1 through 6.

TABLE 1 Overview of Mapping Between Individual BRT Elements and Performance Measures

BRT Element	Sub-Elements	Performance Measures				
		Travel Time	Reliability	Image and Identity	Safety and Security	Capacity
Running Way	Segregation	■	■	■	■	■
	Differentiation/Marketing			■		
	Guidance	■		■	■	
Stations	Station Type	■		■	■	■
	Platform Height	■	■	■	■	■
	Platform Layout	■	■			■
	Passing Capability	■	■			■
	Station Access			■	■	
Vehicles	Vehicle Configuration	■	■	■	■	■
	Aesthetic Enhancements			■	■	
	Passenger Circulation Enhancement	■	■	■	■	■
	Propulsion Systems	■		■		
Fare Collection	Collection Process	■	■	■		■
	Transaction Media	■	■	■	■	■
	Structure	■		■		■
Intelligent Transportation Systems	Transit Signal Prioritization	■	■	■		■
	Driver Assist and Automation	■	■	■	■	■
	Operations Management	■	■		■	■
	Passenger Information Systems	■	■	■	■	
	Safety and Security Technologies				■	
	Support Technologies					■
Service and Operating Plans	Route Length		■			
	Route Structure	■		■		
	Service Span		■			
	Service Frequency	■	■		■	■
	Station Spacing	■	■			
	Method of Schedule Control	■	■			

TABLE 2 Mapping Between Individual BRT Elements and Travel Time Performance Measures

BRT Element	Sub-Elements	Travel Time		
		Running Time	Station Dwell Time	Waiting and Transfer Time
Running Way	Segregation	■		
	Differentiation/Marketing			
	Guidance			
Stations	Station Type			■
	Platform Height		■	
	Platform Layout		■	
	Passing Capability	■		
	Station Access			
Vehicles	Vehicle Configuration		■	
	Aesthetic Enhancements			
	Passenger Circulation Enhancement		■	
	Propulsion Systems			
Fare Collection	Collection Process		■	
	Transaction Media		■	
	Structure			
Intelligent Transportation Systems	Transit Signal Prioritization	■		
	Driver Assist and Automation	■	■	
	Operations Management			■
	Passenger Information Systems			■
	Safety and Security Technologies			
	Support Technologies			
Service and Operating Plans	Route Length			
	Route Structure			■
	Service Span			
	Service Frequency		■	■
	Station Spacing	■		
	Method of Schedule Control	■	■	■

TABLE 3 Mapping Between Individual BRT Elements and Reliability Performance Measures

BRT Element	Sub-Elements	Reliability		
		Running Time Reliability	Station Dwell Time Reliability	Service Reliability
Running Way	Segregation	■		
	Differentiation/Marketing			
	Guidance			
Stations	Station Type			
	Platform Height		■	
	Platform Layout		■	■
	Passing Capability	■		■
	Station Access			
Vehicles	Vehicle Configuration		■	
	Aesthetic Enhancements			
	Passenger Circulation Enhancement		■	
	Propulsion Systems			
Fare Collection	Collection Process		■	
	Transaction Media		■	
	Structure			
Intelligent Transportation Systems	Transit Signal Prioritization	■		■
	Driver Assist and Automation	■	■	
	Operations Management	■	■	■
	Passenger Information Systems			■
	Safety and Security Technologies			
	Support Technologies			
Service and Operating Plans	Route Length	■		
	Route Structure			
	Service Span			■
	Service Frequency		■	■
	Station Spacing	■		
	Method of Schedule Control		■	

TABLE 4 Mapping Between Individual BRT Elements and Image and Identity Performance Measures

BRT Element	Sub-Elements	Image and Identity	
		Brand Identity	Contextual Design
Running Way	Segregation	■	■
	Differentiation/Marketing	■	
	Guidance		
Stations	Station Type	■	■
	Platform Height		
	Platform Layout		
	Passing Capability		
	Station Access		
Vehicles	Vehicle Configuration	■	
	Aesthetic Enhancements	■	■
	Passenger Circulation Enhancement		
	Propulsion Systems	■	
Fare Collection	Collection Process	■	
	Transaction Media	■	
	Structure		
Intelligent Transportation Systems	Transit Signal Prioritization	■	
	Driver Assist and Automation	■	
	Operations Management		
	Passenger Information Systems	■	
	Safety and Security Technologies		
	Support Technologies		
Service and Operating Plans	Route Length		
	Route Structure		
	Service Span		
	Service Frequency		
	Station Spacing		
	Method of Schedule Control		

TABLE 5 Mapping Between Individual BRT Elements and Safety and Security Performance Measures

BRT Element	Sub-Elements	Safety and Security	
		Safety	Security
Running Way	Segregation	■	
	Differentiation/Marketing		
	Guidance	■	
Stations	Station Type		
	Platform Height	■	
	Platform Layout		
	Passing Capability		
	Station Access		
	Station Design		■
Vehicles	Vehicle Configuration	■	
	Aesthetic Enhancements		■
	Passenger Circulation Enhancement		
	Propulsion Systems		
Fare Collection	Collection Process		■
	Transaction Media		■
	Structure		
Intelligent Transportation Systems	Transit Signal Prioritization		
	Driver Assist and Automation	■	
	Operations Management		■
	Passenger Information Systems		
	Safety and Security Technologies	■	■
	Support Technologies		
Service and Operating Plans	Route Length		
	Route Structure		
	Service Span		
	Service Frequency		
	Station Spacing		
	Method of Schedule Control		
	Operating Procedures		

TABLE 6 Mapping Between Individual BRT Elements and Capacity Performance Measures

BRT Element	Sub-Elements	Capacity
		Person Capacity
Running Way	Segregation	■
	Differentiation/Marketing	
	Guidance	
Stations	Station Type	■
	Platform Height	■
	Platform Layout	■
	Passing Capability	■
	Station Access	
	Station Design	
Vehicles	Vehicle Configuration	■
	Aesthetic Enhancements	■
	Passenger Circulation Enhancement	■
	Propulsion Systems	
Fare Collection	Collection Process	
	Transaction Media	
	Structure	
Intelligent Transportation Systems	Transit Signal Prioritization	
	Driver Assist and Automation	
	Operations Management	
	Passenger Information Systems	
	Safety and Security Technologies	
	Support Technologies	
Service and Operating Plans	Route Length	
	Route Structure	
	Service Span	
	Service Frequency	■
	Station Spacing	
	Method of Schedule Control	
	Operating Procedures	■

The previous discussion and associated set of six overview tables provided the correspondence between individual BRT system elements and performance measures in qualitative terms, that is, which BRT elements affect particular performance measures. We present in Table 7, in quantitative terms, a sample of impacts experienced by individual bus rapid transit systems in terms of specific measures of performance. Details for numerous other BRT systems may be found in (2).

TABLE 7 BRT Systems by Elements and Performance

System Elements	System Performance
Boston Silver Line • Primarily dedicated arterial lane together with mixed flow lanes; adjacent mixed flow lane provides opportunity for passing capability; lane differentiation provided with special striping • ITS technologies include transit signal priority, passenger information provided at the station, and advanced communication and dispatch system together with an AVL system • Platform height consists of the standard curb configuration • Specialized BRT vehicle — stylized articulated (60 foot) low-floor bus — is used • Fare media includes swipe card, cash, and paper with on-board payment • Schedule-based control is used • Bus shelter/station has pedestrian focus • Service is provided all day with 4 minute headways during the peak periods • The route is approximately 2.4 miles in length • Hybrid internal combustion engine - compressed natural gas propulsion system is used • Emergency telephones are available for security monitoring	*Boston Silver Line* • 26% travel time reduction compared to local bus • 29% travel time reduction as reported by MBTA • 73.2% of surveyed passengers rate travel time as “above average” or “excellent” • 60.2% of passengers rated service frequency “above average” or “excellent” • 65% of surveyed passengers rated Reliability “above average” or excellent • 55.6% of passengers rated personal safety as either “above average” or “excellent”
Honolulu City Express! • Arterial mixed flow lanes; adjacent mixed flow lanes provide passing capability • ITS technologies include transit signal priority, and advanced communication and dispatch system together with an AVL system, and passenger information via telephone and the Internet; lane differentiation is provided by means of concrete barriers on highway lane • Platform height consists of the standard curb configuration with space accommodating one vehicle • Conventional articulated 60-foot low floor vehicle is used • Bus shelter/station has pedestrian focus • Fare media includes cash and paper with on-board payment • Schedule-based control method is employed • Service is provided all day with service frequency every 11 minutes during peak periods • Route lengths are approximately 19.6, 7.0, and 30.0 miles, for City Express A, B, and C, respectively • Hybrid internal combustion engine – ultra low-sulfur diesel propulsion system is used	*Honolulu City Express!* • 20% and 7% travel time reduction compared to local bus for City Express B and C, respectively

<table>
<tr><th>System Elements</th><th>System Performance</th></tr>
<tr><td>Los Angeles Metro Rapid Wilshire
Mixed flow lane with adjacent mixed flow lane for passing capability
ITS includes transit signal priority, advanced communication and dispatch system together with an AVL system, and passenger information via telephone and the Internet
Platform height consists of the standard curb configuration with space accommodating one vehicle
Conventional standard 40-foot low floor vehicle with large windows
Fare media includes cash and paper with on-board payment
Headway-based control method is employed
Enhanced shelters/stops with pedestrian focus
Route structure is single route overlayed onto local network
Service is provided all day with service frequency every 2-4 minutes during peak periods
Route length is approximately 26 miles
Hybrid internal combustion engine - compressed natural gas propulsion system is used</td><td>Los Angeles Metro Rapid Wilshire
38% reduction in travel time along corridor compared to former Limited Bus service along Wilshire
44% increase in total corridor ridership
Passengers rate service 3.8 out of a max of 5 compared to 3.4 for former Limited Bus service along Wilshire corridor
Passengers rate service frequency 3.8 out of 5 compared to 3.1 for former Limited Bus
Passengers rate service 3.9 out of max of 5 for personal safety on buses compared to 3.4 for former Limited Bus</td></tr>
<tr><td>Orlando Lymmo
At-grade exclusive lane; lane differentiation provided by concrete pavers
Station spacing is approximately 900 feet
ITS includes AVL system and passenger information at station, on vehicle and via PDAs
Platform height consists of the standard curb configuration with space accommodating two vehicles
Conventional standard 35-foot vehicles are used
Fares are free
Headway-based control
Enhanced shelters/stops with pedestrian focus are used; one park-and-ride lot
Service is provided all day with service frequency every 5 minutes during peak periods
Route length is approximately 3 miles
Internal combustion engine vehicles are used
Security is provided via voice and video monitoring</td><td>Orlando Lymmo
Customer perceptions of attractiveness is rated 93 out of a max of 100
General customer satisfaction is rated a mean of 4.4 out of 5.0; majority of passengers have improved their opinions of public transit</td></tr>
</table>

System Elements	System Performance
Oakland Rapid San Pablo Corridor • Mixed flow lane with adjacent mixed flow lane for passing capability • Platform height consists of the standard curb configuration with space accommodating one vehicle • ITS includes transit signal priority, automated dispatch, AVL, and vehicle monitoring system and passenger information at station, on vehicle, via Internet, with PDAs • Service is provided all day with service frequency every 5 minutes during peak periods • Stylized standard 40-foot low floor vehicle with large windows • Fare media includes cash and paper with on-board payment • Headway-based control method is employed • Enhanced shelters/stops with pedestrian focus • Route length is 14 miles • Hybrid internal combustion engine – ultra low-sulfur diesel propulsion system • Service frequency 12 minute headways during peak periods	*Oakland Rapid San Pablo Corridor* • 21% travel time reduction compared to local service along San Pablo • 83% of riders rate service as "Good" or "Excellent" compared to 72% with same ratings two years prior
Pittsburgh West Busway • Grade-separated exclusive lanes for 4.3 miles with 0.4 miles of mixed flow arterial • Passing lanes are provided at stations • Stations are designated with enhanced lighting; park-and-ride lots • ITS includes transit signal priority, collision warning, and AVL systems • Station spacing is every three-fourths of a mile • Platform height consists of the standard curb configuration with space accommodating two to three vehicles • Conventional standard (40-foot) and articulated vehicles • Fare media includes cash and paper with on-board payment • Schedule-based control method is employed • Service is provided all day with service frequency every 1 minute during peak periods • Hybrid internal combustion engine – diesel propulsion system •	*Pittsburgh West Busway* • 26% travel time reduction compared to systemwide travel times • Customer perception shows 85% of passengers report shorter travel times with an average reduction of 14 minutes • 78% of passengers perceived reduced wait time • 52% of passengers reported improvement in transfer process • 68% of passengers perceive service has improved schedule adherence • 91% of passengers indicated service was "Very Important" or "Fairly Important" in their decision to start using the West Busway

2.4 Costs Associated with Bus Rapid Transit System Elements

The U.S. General Accounting Office conducted a study in 2001 (3) that compared the capital costs and operating costs with light rail transit and also examined other characteristics of these two transit modes including flexibility, ease with which it could be phased in to service, stimulus for community economic development, and environmental aspects of bus rapid transit systems investment with that of light rail transit systems. The report considered 38 bus rapid transit projects within the U.S. including demonstrations and those systems already operational at the time and in revenue service. Since this study, there have been two additional studies ─ one that began in 2004 and is still on-going and now scheduled to be complete in the summer of 2006 and the other whose period of performance was 2004 and 2005 ─ that have delved deeper and probed further into the capital costs associated with bus rapid transit systems and have collected and reported on disaggregated capital cost data for bus rapid transit systems. Findings from the GAO study, however, are reported only in aggregate terms consisting of total capital cost and total capital cost per mile of system length (See Table 8). The first of these two studies is TCRP Project A-23A, itself a follow-on to TCRP Project A-23 that in 2003 produced a two-volume set of Case Studies and Implementation Guidelines for bus rapid transit. The quantitative data from TCRP Project A-23 were also fairly aggregate with cost breakdowns by BRT components not identified for most of the BRT systems surveyed. The objective of TCRP Project A-23A is to determine the costs, impacts, and effectiveness of implementing selected BRT components. An interim report deliverable from Project A-23A was produced in 2004 and provides disaggregated capital cost data for selected BRT elements (2). The second of the two studies was performed by the Institute of Transportation Studies at the University of California, Los Angeles' School of Public Affairs, which conducted this study to better understand two fairly common yet different views about bus rapid transit (5). In the authors' own words, "Bus Rapid Transit (BRT) is the hot new concept in public transit circles these days. Touted by some as leading a new wave of rail-like, high-speed, rubber-tired rapid transit lines, and by others as a cost-effective way to upgrade both the quality and image of local bus service, bus rapid transit has quickly come to mean many things to many people". A natural question arises to the forefront: What view of BRT predominates, at least in North America? The authors explored this question by examining the cost-effectiveness of fourteen current and planned [at the time of publication] BRT systems in North America.

The authors of the GAO study first developed a three-way conceptual framework with which to perform their analysis and assist in classifying bus rapid transit systems in terms of their running ways, that is, whether a BRT system operated on 1) arterial streets in mixed traffic, 2) high-occupancy vehicle lanes on freeways or 3) exclusive busways, grade-separated. For bus rapid transit systems on arterial streets, there is generally no to minimal infrastructure needs as buses operate in mixed-flow lanes. For bus rapid transit systems operating in HOV lanes on freeways or other type of limited access roadway, minimal changes to re-designate lanes are required to provide separate through-way lanes and queue jump lanes. For bus rapid transit on busways, extensive construction is needed for new busways and other facilities, as bus will be operating on exclusive bus lanes potentially in grade-separated conditions.

TABLE 8 Capital Costs of Bus Rapid Transit Systems

Types of Running Ways	Total Capital Cost (Millions $2000)	System Length (miles)	Cost per Mile (Millions $2000)
Arterial Streets			
Wilshire-Whittier (Los Angeles)	5.01	25.7	0.19
Ventura (Los Angeles)	3.26	16.7	0.20
Lymmo (Orlando)	22.09	2.3	9.60
		Average cost per mile = $0.68 M	
HOV Lanes			
I-30 (Dallas)	26.75	5.2	3.64
I-35E (Dallas)	13.96	6.6	1.76
I-25 (Denver)	248.34	6.6	37.63
Southwest US 59 (Houston)	147.21	14.3	10.29
Eastex US 59 (Houston)	150.43	20.2	7.45
I-5 (Seattle)	10.98	6.0	1.83
I-405 (Seattle)	14.42	6.0	2.4
I-15 (San Diego)	41.74	8.0	5.22
		Average cost per mile = $9.0 M	
Busways			
Katy I-10 (Houston)	154.16	15.3	10.08
North I-45 (Houston)	206.88	19.9	10.40
Northwest US 290 (Houston)	150.87	13.5	11.18
Gulf I-45 (Houston)	131.46	15.5	8.48
El Monte Busway I-10 (Los Angeles)	127.25	11.0	11.57
Miami	63.12	8.5	7.43
South Busway (Pittsburgh)	63.3 4	4.3	14.73
East Busway (Pittsburgh)	174.54	6.8	25.67
West Busway (Pittsburgh)	275.00	5.0	55.00
		Average cost per mile = $13.5 M	

Source: "Mass Transit Bus Rapid Transit Shows Promise", U.S. General Accounting Office, GAO-01-984, September 2001 (based on data from FTA and individual transit agencies).

Continuing to use this three-way typology, while maintaining consistency with that of the GAO Report, also allows for a more accurate comparison among different bus rapid transit systems. For example, the per-mile cost to build a bus rapid transit system involving a complete and extensive re-build of corridor infrastructure including street pavement, sidewalks, curbs, stations, signalization, and public utilities cannot be directly compared to the same unit cost for another system, which operates on surface arterial streets that required few, if any, right-of-way improvements as part of its implementation. While the UCLA study maintains this typology, the TCRP Project does not strictly adhere to it, which poses additional challenges to compare findings across these two studies. Moreover, notwithstanding these differences, the UCLA and TCRP studies are generally consistent with each other in those areas where they do overlap. Table 9 depicts those cities of case studies for which disaggregate cost breakdowns were performed for the TCRP and the UCLA studies.

TABLE 9 Bus Rapid Transit Systems Disaggregated Capital Cost Studies

BRT Case Study Cities Examined	Project/Facility Name	TCRP Study	UCLA Study
Adelaide	South Australia O-Bahn	X	
Boston	Silver Line	X	
Brisbane	South East Busway	X	
Cleveland	Euclid Corridor	X	X
Detroit	SpeedLink		X
Eugene	Franklin Corridor EmX		X
Hartford	New Britain-Hartford Busway	X	X
Honolulu	City / County BRT		X
Las Vegas	MAX	X	
Los Angeles	Wilshire (I)	X	X
	Ventura	X	X
	Wilshire (II)	X	X
Miami	South Miami-Dade Busway	X	X
Nashville	Urban Core BRT		X
Oakland	San Pablo Rapid		X
Orlando	Lymmo		X
Ottawa	Transitway	X	
Pittsburgh	East Busway	X	
	West Busway	X	
San Jose	Line 522 BRT		X
Vancouver	Line 98-B	X	X

A thumbnail sketch of the bus rapid transit systems that were investigated by either the TCRP project or UCLA project or both are presented in Table 10. We have kept the three-way typology division previously established.

TABLE 10 Thumbnail Sketch for BRT Systems

Arterial Streets	HOV Lanes	Busways
Oakland, CA (San Pablo Corridor) • Arterial street operation in mixed flow traffic • $283 K / mile (16 miles) Los Angeles, CA (Wilshire I and Ventura I) • Arterial street operation in mixed flow traffic • $195 K / mile (25.7 miles and 16.7 miles, respectively	San Jose, CA (Line 522) • Selective use of queue jump lanes • $1.2 M / mile (27 miles) • 40 articulated low-floor, standard-design coaches at $465 K / bus Vancouver, BC (98-B Line) • Exclusive median busway • $1.8 M / mile (9.9 miles) • 28 articulated low-floor buses at $405 K / bus Los Angeles, CA (Wilshire II) • Dedicated lane on arterial streets • $5.8 M / mile (25.7 miles) • 97 articulated buses at $848.5 K / bus Detroit, MI (SpeedLink) • Exclusive lane arterial operation • No new roadbed reconstruction • $6.3 M / mile (247.5 miles) Orlando, FL (Lymmo) • Exclusive lane arterial operation • $9.1 M / mile (2.3 miles) Nashville, TN (Urban Core BRT) • Exclusive bus lanes on arterial streets • $10.7 M / mile (4.2 miles)	Boston, MA (The Silver Line) • Combination of interior bus lanes, curb bus lanes, and contraflow bus lanes • 44 60-foot CNG buses • $38 M total cost. Brisbane, AU (South-East Busway) • 10.5 miles long; 1.2 miles elevated; 1.6 miles tunnel • $330 M total cost • 10 major stations • No new buses used on dedicated routes Eugene, OR (Eugene-Springfield BRT) • Exclusive bus lanes or guided busways • Within ROW of existing arterials • $3.5 M / mile (4 miles) Las Vegas, NV (MAX) • 7.8-mile exclusive bus lane • 10 60-foot Civis buses • $19.2 M total cost Miami, FL (South Miami-Dade Busway Extension) • Exclusive two-lane busway on an abandoned freight right-of-way • $7.3 M / mile (11.5 miles) Honolulu, HI (City/County BRT) • Exclusive median bus lanes • $11.5 M / mile (32.2 miles) Hartford, CT (New Britain-Hartford Busway) • Exclusive two-lane busway built on abandoned freight right-of-way • Use of articulated buses • $15 M / mile (9.6 miles) Cleveland, OH (Euclid Corridor BRT) • Complete rebuild of Euclid Ave. • Exclusive center median busway with platform stations • Enhanced pedestrian zones • New exclusive bus and auto lanes • $168.4 M total cost • 20 diesel/electric articulated 60-foot buses at $1.2 M each. Pittsburgh, PA (East Busway Extension) • Exclusive bus lanes • $30 M / mile (2.3 miles) Pittsburgh, PA (West Busway) • Exclusive bus lanes • $59 M / mile (5.1 miles) Ottawa, CA (Transitway) • Multiple running way types; 42% on grade-separated busway and 19% on highway shoulder lanes • $324.6 M total cost Adelaide, AU (O-Bahn) • Primarily grade-separated facility • $9.1 M cost / mile (7.5 miles)

Sources:

"Light-Rail-Lite or Cost Effective Improvements to Bus Service? Evaluating the Costs of Implementing Bus Rapid Transit", Journal of the Transportation Research Board, 2005.

"Cost and Effectiveness of Selected Bus Rapid Transit Components – Interim Report", Transit Cooperative Research Program, Transportation Research Board, National Research Council, July 2004.

Each of these two studies disaggregated the overall total development cost for each project into individual components and results are presented in Table 11, which depicts the relative roles of items such as property acquisition, intelligent transportation systems, stations, vehicles, running way, and design/administration costs. The ITS category includes transit signal priority, advanced vehicle location, and bus arrival information systems. The "Other" category includes items such as contingency costs, maintenance facilities' costs, and marketing costs. For some projects, such as Los Angeles' Metro Rapid service on the Wilshire-Whittier and Ventura corridors the only cost components are for stations and ITS. While for other projects, such as Cleveland, Hartford, and Vancouver, each identified cost component contributes some amount to the total cost of development.

TABLE 11 Percentage Share of Disaggregated BRT System Development Costs

	Land Acquisition	Running Way	Stations	Vehicles	ITS	Design, Administration, Supervision	Other	Total Cost ($M)
Adelaide	5.9 %	54.5 %	6.5 %	22.5 %	0 %	10.5	0 %	67.9
Boston	0 %	60.8 %	9.6 %	27.6 %	2.0 %	0 %	0 %	37.8
Brisbane	0 %	79.6 %	2.5 %	0 %	2.0 %	0 %	15.9 %	330.1
Cleveland	8.1 %	26.3 %	10.8 %	12.8 %	5.1 %	26.1	10.8 %	168.4
Eugene – EmX	4.1 %	57.6 %	12.2	—	0.4 %	10.4 %	15.2 %	15.7
Hartford	8.3 %	37.1 %	19.7 %	7.7 %	0.7 %	22.6 %	3.9 %	145.0
Honolulu – City/County BRT	0.0 %	25.1	11.0 %	58.9 %	1.7 %	0.0 %	3.4 %	903.9
Las Vegas	0 %	0 %	23.4 %	63.0 %	2.8 %	0 %	10.5 %	19.2
Los Angeles – Wilshire-Whittier	0 %	0 %	48.7 %	0 %	51.3 %	0 %	0 %	5.0
Los Angeles – Ventura	0 %	0 %	48.8 %	0 %	51.2 %	0 %	0 %	3.3
Los Angeles – Phase II Wilshire-Whittier	0 %	2.8 %	4.0 %	35.4 %	0 %	9.3	48.4 %	232.2
Miami – Busway Extension	28.2 %	53.8 %	0.0 %	2.3 %	0.0 %	11.4 %	4.3 %	85.5
Nashville – Urban Core BRT	0.0 %	9.5 %	21.0 %	15.7 %	13.9 %	13.3 %	26.5 %	53.5
Oakland – San Pablo	0 %	2.6 %	44.1 %	0 %	36.1 %	0.6 %	16.6 %	4.5
Ottawa	0 %	69.0 %	27.6 %	0 %	0 %	0 %	3.4 %	324.6
Pittsburgh – East Busway	14.5 %	44.2 %	2.9 %	0 %	0 %	24.4 %	13.4 %	68.8
Pittsburgh – West Busway	8.8 %	73.9 %	0.9 %	0 %	0 %	0 %	16.0 %	299.1
San Jose – Line 522	0.0 %	36.2 %	13.2 %	36.6 %	4.9 %	6.7 %	2.3 %	50.8
Vancouver	8.9 %	22.8 %	6.3 %	33.4 %	11.2 %	6.5 %	10.9 %	32.8

2.5 Representative Deployment Phases for Bus Rapid Transit Systems

Each of BRT's primary elements ─ stations, running ways, vehicles, service plan, and intelligent transportation systems ─ may be deployed in ways that range from very simple to quite complex and the availability of these options exhibit an inherent deployment flexibility that allows the agency developing, implementing, and eventually operating the system to select those elements that match the environment in which the system would operate, including the specifics of the market for which it is being considered and the constraints (institutional, technical, budgetary, etc.). For example, stations may range from simple stops to so-called "super stops" and shelters to high platform structures, adjacent to park and ride lots with amenities and other services. Another example, for running ways, shows that BRT vehicles can operate in mixed traffic with transit signal priority, far side stops and low-floor buses or be on fully grade-separated busways/transitways.

Thus, from the definition of bus rapid transit (Section 1), we highlight certain aspects that are particularly relevant to deployment:

- Flexibility
- Designed to be appropriate to the market it serves
- May be incrementally implemented in a variety of environments.

These features are closely related to one another and to the notion of how a BRT system is developed and deployed because implicit in them is the idea of adapting to changes in contextual circumstances occurring over time.

A transit agency may be motivated by a multitude of factors in determining deployment phases for a bus rapid transit system, especially the initial phase, that is, how to get started. The importance of incremental development to BRT cannot be overstated, as the authors in (1) assert:

> "In many cases, it may be useful to identify a BRT segment for immediate, early implementation. Early action is essential to retain community support and continuity of public agency staff. This will demonstrate BRT's potential benefits as soon as possible to riders, decision makers, and the public at relatively little cost while still enabling system expansion and possible future upgrading. The initial segment could include curb bus lanes that may be upgraded to busways in the future. A BRT line can also serve as a means of establishing the transit market for a possible future rail line."

2.5.1 Review of Bus Rapid Transit Deployment Processes

We reviewed BRT system corridors internationally, whether currently operational or not, from the perspective of *deployment phasing*, including history and/or plans for implementation. Our objective was to determine whether systems were deployed as one complete package or their deployment was phased in, and to collect information about the reasons for phased deployment. These BRT systems include those in North America, Australia, Europe, and South America.

At the planning stage there is a vision for the final BRT system: its elements, characteristics of its elements, benefits, cost and the estimated resulting service level and ridership. We consider a BRT system to be deployed as one package if this final vision is deployed and opened to operation. In short, when the system starts operating everything is in place. We consider a BRT system to be deployed in phases if when the system opens for operation it does not have all the features of the final system. Rather, an initial or intermediate stage is deployed that does not have all the elements/characteristics or benefits of the final system. BRT can be phased-in in terms of its:

- Location – phase one may be only a section of the final system
- Elements – not all BRT elements are deployed in phase one. For example, BRT vehicles acquired, or smart card technologies implemented at a later time. Or not all elements are deployed throughout the whole system. For example, not all jurisdictions agree to implement signal priority.
- Characteristics of elements – for example, advanced features are added to the new BRT station as budget becomes available, such as *Next Bus* information sign

Such phased deployment can be planned, for example, in order to gain public support, or required by internal constraints such as financial/budgetary issues, or external constraints such as inter-jurisdictional disagreements.

It is reported whether deployment was in phases and what those phases were. The reasons for phased deployment are not documented, although in most cases can be discerned from the available information. Findings are summarized at the end of this section in Table 12.

2.5.1.1 North America

We further subdivide the North American case studies into those within and outside California.
<u>California</u>
Alameda and Contra-Costa Counties
San Pablo Corridor
In June 2003 AC Transit put into revenue service its first bus rapid transit line primarily along the San Pablo Corridor of California Route 123 in the East Bay portion of the San Francisco Bay Area. The BRT line is 14 miles long running through seven cities traveling on a State Highway under Caltrans jurisdiction. AC Transit has named this BRT service the “Rapid” and each Rapid bus stop/shelter and bus is adorned with the same “Rapid” red branding and logo to enhance the visibility of this service. Buses are new 40-footers with low floors and equipped with three doors. Each Rapid Bus stop/shelter is also equipped with a NextBus bus arrival information system. Transit signal priority has also been implemented along the San Pablo Corridor. There are a limited number of stops ─ 26 stops over the 14 mile corridor ─ spaced approximately ½ mile apart. Stops have been moved to the far side of the intersection. There are also queue bypass lanes to allow buses to bypass extensive queues at intersections.

Telegraph Avenue ─ International Boulevard Corridor
AC Transit is planning to implement its second bus rapid transit system along the Telegraph – International Boulevard corridor in the East Bay of the San Francisco Bay Area. Bus Rapid

Transit was chosen as the locally preferred alternative as a result of a Major Investment Study that AC Transit conducted along this alignment. The corridor is 18 miles long with a plan for 33 BRT stops at an average stop spacing of approximately 0.55 miles. AC Transit currently estimates that while "most" of the 18-mile alignment will have an exclusive transit lane only 1.5 miles are definitely off-limits because of its potential impact on traffic circulation. More definitive data must wait until the completion of an ongoing Environmental Impact Report for the corridor.

Los Angeles County
Wilshire-Whittier Corridor/Wilshire BRT
After a visit by officials from the Los Angeles County Metropolitan Transportation Authority (MTA) to Curitiba, Brazil to view its bus rapid transit system, MTA commissioned a study to assess the feasibility of BRT in Los Angeles. The study's findings, which initiated the Metro Rapid Program in 1999, recommended that MTA, in partnership with the City of Los Angeles Department of Transportation (LADOT), conduct a demonstration along two to three major arterials that had strong ridership and favorable characteristics for BRT development. In June 2000, MTA and LADOT began the demonstration of its new bus rapid transit service, called Metro Rapid, along two of the city's most heavily traveled urban-suburban corridors in terms of ridership: Wilshire-Whittier Boulevards and Ventura Boulevard corridors. MTA conducted a survey of riders along these corridors to assess riders' points of view about service. Survey findings provided MTA input to develop its goals for service improvement.

MTA's implementation of Metro Rapid along the 27-mile long Wilshire-Whittier corridor was planned for two phases with Phase I consisting of the following elements (modeled after Curitiba's BRT system) operating in mixed traffic:

- Low floor buses fueled by compressed natural gas
- Transit signal priority
- Stops equipped with *Next Bus* message information signs
- Reduced the number of stops from 135 to 30
- Implemented a new operation policies:
    - Faster buses can and are even encouraged to pass slower buses
    - Passengers are encouraged to alight the bus from the backdoor
- Stops placed on the far side of intersections
- Reduced headway to 2.5 minutes during peak periods (7-10 AM, 4-7 PM).
- Introduced prepaid fare payment
- Color-coded Metro Rapid buses and stops/stations using red and white with "Metro Rapid" designated on each bus. Use of this design and colors on vehicles and stations help to promote and instill a unique identify of the service in passengers' minds.

In terms of the level of Metro Rapid's staged deployment, some of the key attributes that MTA wanted to deploy could not be immediately implemented to their full extent due to budgetary and/or institutional constraints. However, MTA wanted to package together and deploy as many BRT attributes as possible as soon as possible in order to make a substantive and positive impression with the public, especially current passengers. This led MTA to reject an FTA suggestion to implement each BRT element separately to more readily determine each element's individual impacts. MTA's concern was that implementing each element separately, instead of making a big splash with the public, would provide benefits in drips and drabs and that this would not be a good marketing strategy. MTA correctly assessed the situation as the Metro Rapid Bus Phase I was hugely successful and contributed to MTA not only receiving a green light for Phase II but also getting the go-ahead for an expansion of the Metro Rapid Program to more than two dozen Metro Rapid Lines throughout the county by 2009. While these Lines will not be configured in exactly the same manner, there is a core set of BRT elements that each will be implemented with.

The entire 27-mile length of Metro Rapid's Wilshire-Whittier corridor was implemented in Phase I however, even within Phase I, additional sub-phases were necessary as not all other BRT elements were deployed along the entire corridor length. For example, signal priority was deployed along the corridor only in the City of Los Angeles, which comprised approximately half the corridor length. Other corridor cities, e.g., Santa Monica, Beverly Hills, initially refused to implement signal priority until they were convinced of demonstrable benefits from it that outweighed relinquishing jurisdictional control over their traffic signals. Instead of requiring an all-or-nothing deployment of signal priority along the whole corridor to accommodate early institutional constraints and thus potentially contributing to many years' delay of the technology, MTA and LADOT opted for full technical deployment though partial institutional deployment. The benefits of transit signal priority have been demonstrated and are being used to convince the other cities to agree to implement signal priority along the entire corridor.

The Phase I Demonstration program has increased speeds, improved reliability, and attracted new riders. However, several areas emerged where additional refinements are desirable:

- Continue to improve bus-operating speeds by completing the transit signal priority installation along the corridor outside Los Angeles.
- Introduce exclusive bus lanes where feasible and give priority to arterial segments with chronic, debilitating, traffic congestion delay.
- Provide more passenger capacity by introducing larger vehicles during peak periods rather than increasing service frequency.
- Reduce station dwell times by testing and introducing off-vehicle fare collection systems such as "proof of payment" and introducing high-capacity buses to manage standees within standards and avoid gross aisle congestion delays.

In June 2001, MTA adopted bus rapid transit for the western half of the Wilshire-Whittier corridor, called the Wilshire BRT, as the Locally Preferred Alternative. The MTA completed environmental clearance for this portion of the corridor in August 2002 with construction bids accepted in 2003 and completion by late 2005. This portion of the corridor comprises Phase II of Metro Rapid's implementation. Phase II will add the following elements:

- Peak period exclusive bus lanes in city of Los Angeles by means of a three-stage demonstration (field test & evaluation) of dedicated bus lane segments during peak periods
    - Stage I: Between Centinela and Federal Avenue, no curbside traffic diversion though loss of peak period parking; currently in operation and under evaluation
    - Stage II: Between La Brea and San Vicente, curbside traffic diversion

    - Stage III: Between Western and La Brea, curbside lanes narrower than transit lane standard; demonstration of electronic guidance integrated into demonstration
- Smoother ride on rebuilt concrete lanes
- Smartcard fare payment read by on-board validators at each door
- Ticket vending machines at bus stops to reduce boarding time
- Upgrade/enhance existing stops/shelters with amenities and add “gates” that will align where passengers wait with doors of stopped bus for faster boarding.
- Expanded use of transit signal priority system (outside city of L.A.) requiring agreements with neighboring cities (Beverly Hills and Santa Monica)
- Articulated 3-door buses to increase bus capacity and reduce peak-period crowding
- Multiple-door entry and exit
- New bus interior designs for greater passenger comfort
- Maintains all existing landscaped medians and left turn pockets

MTA has proposed following capital projects to address specific jurisdiction-by-jurisdiction concerns along the Wilshire BRT:

1. Curb lane repair and reconstruction within city of Los Angeles
2. New stations along corridor outside city of L.A.
3. New station at VA Hospital
4. Demonstration Program for each transit lane
5. Bus Storage and Maintenance Facility in Los Angeles CBD
6. Park-&-Ride facilities on MTA-owned land

Orange County

The Orange County Transportation Authority (OCTA) decided in February 2005 to proceed with considering options for rapid transit even though federal funding for FY 2004-2005 would not be forthcoming for the previously planned CenterLine LRT project, a 9.3-mile starter segment from the Depot at Santa Ana to John Wayne Airport. The LRT project is on hold while OCTA explores other mass-transit solutions including bus rapid transit systems.

The 1990 passage of a one half-cent sales tax earmarked for transportation projects included funding for a rapid-transit system. Originally, OCTA selected LRT as the preferred alternative for this corridor. The project secured approximately 50 percent of the required funding and preliminary engineering for the project was completed, however, the project did not receive federal funding this year, resulting in OCTA’s decision to study other options.

OCTA is also developing a process to insure consistency between future work on the rapid-transit master plan in conjunction with recently begun efforts to revise OCTA's long-range transportation plan.

Riverside,

In 2002 the Riverside Transit Agency (RTA) began planning for bus rapid transit by establishing an ad hoc committee to study the BRT option. RTA engaged the University of California (Berkeley, Los Angeles, and Riverside campuses) to perform a two-year feasibility planning study to implement bus rapid transit in Riverside County. Riverside County is a low-density sprawling area yet is very fast growing. It has minimal transit use by transit dependent communities. RTA was looking for a cost-effective public transit mode with the potential to increase ridership. In this two-year study, travel patterns were examined by all modes in the county and projected growth was forecasted over a twenty-year time horizon. A range of transit improvements were analyzed and recommendations were subjected to focus group review by the public, current bus riders, and homeowners. The 'Rapidlink' concept was developed that included the following features: skip-stop configuration, automatic vehicle location systems, full bus shelters at stops, bus arrival information signs, maximum of fifteen minute headways, low-floor buses powered by compressed natural gas, transit signal priority, transit merge priority at stations, and a Rapidlink design features (logo, name, color). Rapidlink would be implemented in stages over twelve to fifteen years.

Sacramento Metropolitan Area
In January 2004 Sacramento Regional Transit (RT) implemented the first of its bus rapid transit systems, called the 'Enhanced Bus' or 'EBus' on the Stockton Blvd. corridor of Route 50 between Florin Mall and the Sacramento Central Business District. Three additional EBus corridors were identified by RT as part of its 20-year Vision Plan and include: Watt Avenue, Sunrise Blvd., and Florin Road. The Stockton Blvd. EBus is approximately nine miles long with stations approximately one-half mile apart that operates in mixed traffic and offers weekday service with 15-minute headways between 5:30AM and 7:30PM. The buses are low-floor and CNG-powered and along with the shelters, are designed with a blue and yellow color scheme with the 'E' logo. The EBus offers transit signal priority and queue jumpers at 'E' shelters. Information is provided to passengers on-board the buses. The 'EBus' is a partnership among RT, the city of Sacramento (Public Works Department), Sacramento County (Department of Transportation), and the Sacramento Area Council of Governments.

San Bernardino
Omnitrans, the primary public transportation service provider in the San Bernardino Valley (SBV), has begun planning to improve its transportation services to address expected growth in population, jobs, and travel demand over the next twenty years. The 'E' Street Corridor, in particular, is the focus of much investigation. This corridor study area is approximately 14 miles long, generally from California State University San Bernardino on the north through downtown San Bernardino, then southeast to Loma Linda University generally following Omnitrans' current bus route 2. It runs through a variety of land uses, from low-density residential development in the north to commercial development along 'E' Street. The San Bernardino CBD has some of the highest concentrations of office and public facilities in the Omnitrans service area. The southern end of the corridor contains significant public, educational and medical facilities.

The corridor supports about 120,000 people and more than 70,000 jobs with the highest job density in the SBV. The corridor contains a sizable number of transit-dependent residents living within a quarter of a mile from a current bus stop who are of low income and/or have no automobile. The corridor also contains a sizable population of residents under 18 and over 65 – another indicator of transit dependency, as over half the population is college age or younger and eight percent is over 65 years of age.

The area is well served by transit. Just over 75 percent of corridor residents and about 77 percent of the jobs lie within one-quarter mile of a bus stop. The corridor has about 24,000 daily riders, the largest number in the SBV. About 3.4 percent of residents use public transit, also the highest percentage in the SBV.

However, transit travel times in the corridor do not compete well with the speed attained by private automobiles. Currently, buses travel in mixed flow with other traffic and stop every few blocks. Many passengers experience long wait times transferring between routes. As a result, travel times on buses are typically two to three times those for autos, and can add 20 to 40 minutes to a trip. Slow buses result in limited mobility for the many people in the corridor dependent on transit for their travel and deters more people who may live and work in the corridor from at least occasionally using transit. Depressed economic conditions exist in the central corridor. Portions of the corridor are viewed as unsafe. Parking capacity is a problem at major corridor activity centers. Traffic conditions create wide variation in travel times for existing buses, particularly near the I-10 freeway where bottlenecks occur often. These variations create scheduling problems and often result in longer travel times for riders.

As a result of these corridor-wide problems, Omnitrans together with the region's metropolitan planning organization, the San Bernardino Associated Governments (SANBAG) and other public agencies are currently studying conceptual alternatives as part of its normal transportation planning process in order to identify their locally preferred alternative for the 'E' Street corridor.

The conceptual alternatives include

- No Action, which would include only existing and already programmed projects and services
- Transportation Systems Management, which would include existing and programmed projects, and the most recent Omnitrans Short Range Transit Plan and other non-capital improvements
- BRT
- LRT

Major milestones of the alternatives analysis include:

- February 2004: Project Initiation and Scoping
- August 2004: Conceptual Alternatives Analysis
- December 2004: Detailed Alternatives Analysis
- June 2005: Selection of Locally Preferred Alternative and Transition to Preliminary Engineering Study

San Diego

In October 2000, the Metropolitan Transit Development Board (MTDB) adopted the Transit First strategy, a strategic plan to define the future role of transit in the region. MTDB determined that a bus rapid transit Showcase Project to demonstrate the Transit First strategy should be pursued and the Downtown San Diego to San Diego State University (SDSU) corridor was selected. MTDB has completed a preliminary planning study of the Showcase Project that identified the route and general station locations. A more detailed study, now underway, is assessing transit signal technology that would be used and is performing an engineering design for the transit lanes and stations.

The Downtown San Diego — SDSU Corridor is 9.9 miles long. Currently, plans call for there to be 17 BRT stops/stations in each direction. The new BRT service is intended to replace at least parts of currently existing lines that cover portions of the new route. Of the 9.9-mile corridor, approximately 3.5 miles will be a transit-only lane. Buses will be able to use the general-purpose lanes when needing to pass. There will be a reserved mostly curb-side bus lane in each direction, so passing will only be needed to get around slower buses or right-turning vehicles or cars accessing the on-street parking. The operating plan has not yet been developed and depends on funding availability, however, preliminary planning calls for 10-minute and 15-minute headways during peak and off-peak periods, respectively.

San Francisco
The Municipal Railway of San Francisco (Muni) began initial consideration of bus rapid transit in the city in 2002 when it produced its 2002 Vision Document. This was followed up in 2004 with the San Francisco Countywide Transportation Plan and implementation of San Francisco's Transit First Policy to develop the city's network of Transit Preferential Streets by means of bus rapid transit. Three corridors were initially selected for further consideration of BRT: Van Ness Avenue, Geary Boulevard, and Potrero Avenue. Also in 2004 was the initiation of the Van Ness Avenue Bus Rapid Transit Study that conducted an assessment of existing conditions and needs for the corridor and development of bus rapid transit alternatives. Currently Muni and the San Francisco Transportation Authority (SFTA) have commissioned an analysis of BRT conceptual alternatives (center or side alignments) in conjunction with an implementation strategy. While it is premature to identify with any certainty what combination of elements will be deployed along the Van Ness corridor, Muni and SFTA are examining dedicated transit lanes that are physically separated from other traffic, distinctive stations and boarding areas, provision of bus arrival information to passengers at stations, transit signal priority, and streetscape improvements and other amenities.

San Mateo
San Mateo County Transit District (SamTrans) is currently studying the potential impacts of transit signal priority systems along routes 390 and 391 on SR 82. It is also in the early planning stages for its Enhanced Bus Network Service. A more complete description may be found in http://www.samtrans.org/stratplan.html Strategic Plan/Short Range Transit Plan.

Santa Clara
The Santa Clara Valley Transportation Authority (VTA) is currently implementing its vision of bus rapid transit along its Line 22 corridor, which provides service along the east-west length of Santa Clara County between the Eastridge Shopping & Transit Center in San Jose to the Caltrain station in Menlo Park. Line 22 is twenty-seven miles long and runs every 10 minutes during weekdays, primarily along El Camino Real (California State Route 82) serving the cities of San Jose, Santa Clara, Sunnyvale, Mountain View, Los Altos, Palo Alto, and Menlo Park. It is VTA's most heavily used line, carrying over 23,000 riders daily and representing 16% of VTA's total bus ridership. The line operates near capacity with many buses at standing room only. Line 22 is supplemented by Line 300, which is a limited stop express service along generally the same corridor. Lines 22/300 connect with regional rail services as well as 55 VTA bus lines. A major connection occurs in downtown San Jose, where Line 22 intersects the north-south Guadalupe Light Rail Line.

VTA is implementing BRT along Line 22 in two phases over the next four years. VTA's new Line 522 replaces Limited Stop Line 300 and supplements Line 22, providing faster, more frequent, and more direct service between Eastridge in San Jose and the Palo Alto Transit Center. In comparison to current Line 300 and Line 22 schedules, travel times may be reduced between 10 and 25 percent. A package of changes will be utilized to transform Line 22 into a BRT corridor. This package will include a combination of the following features:

Phase I (Line 522), which started service in July 2005, consists of transit signal priority, limited stops with station spacing approximately one mile, headway-based schedules, queue jump lanes, near-level boarding, low-floor buses and far side stops.

Future improvements under Phase II will include permanent rail-like stations, more intersections with transit signal priority, real-time station display information, new higher capacity vehicles, exclusive bus lanes, and off-vehicle fare payment. Along with the El Camino/Santa Clara Street/Alum Rock Avenue corridor, Stevens Creek Boulevard and Monterey Highway have also been identified as potential BRT corridors.

Outside California

Boston, Massachusetts

Silver Line BRT

The Massachusetts Bay Transportation Authority (MBTA) has implemented its first bus rapid transit service in the Central Business District of Boston. It is a 4.1-mile long corridor called the Silver Line BRT, which adds a fifth rapid transit line to the MBTA's current system of heavy and light rail transit. The Silver Line is being implemented in three phases. Reference (1) is the primary source of information for this summary:

- Silver Line Phase I is a 2.2-mile long stretch of Washington Street that opened in July 2002 between Dudley Square and the Boston CBD. Sixty-foot articulated buses are operating on a dedicated bus lane along Washington Street. During morning and afternoon peak periods, the Silver Line runs with five-minute headways with a 20-minute trip runtime. Estimated capital cost is $50 million.

- Silver Line Phase II is 1.1 miles in length and connects South Station and the South Boston waterfront by means of an exclusive, underground tunnel. It began revenue service in December 2004. Silver Line Phase II operates with branches serving the waterfront, and industrial and residential areas of South Boston and eventually Boston's Logan Airport. Estimated capital cost is $600 million.

- Silver Line Phase III will link downtown Boston with South Station by means of a tunnel. It is currently in the planning stages, is scheduled to open in 2010 provided funding is available. Estimated capital cost is $700 million. Once Phase III has been implemented and all three sections are physically integrated to form the complete Silver Line system, new 60-foot articulated dual-mode buses will be introduced into revenue service.

Developing a complex BRT line in a major city center can require a long time period, integrated city and transportation planning and continued community support. Construction of the tunnel between South Station and World Trade Center in the South Boston Seaport District was coordinated with the Central Artery/Tunnel project, The Big Dig. The opening of Phase II in the Seaport District coincided with the completion of major new development projects, such as the Boston Convention and Exposition Center (BCEC) and the Boston Marine Industrial Park. Construction of the Phase III tunnel will include the reconstruction of the existing Green Line (LRT) transit tunnel.

While such a phased-in deployment has occurred without all planned technical attributes, it nonetheless allows the part of system to operate and already generate benefits to the community well before the whole system would have been ready in its final state. If the system were not implemented until all three phases were complete, passengers would have had to wait until 2010 to use the Silver Line. In order to foster support for the Silver Line, as budget becomes available, additional technologies will be incrementally implemented to further improve service quality. Thus, it is likely that the MBTA will stagger the introduction of new features rather than waiting to unveil a complete BRT system. The likely sequence of adding features is as follows:

- Talking Buses – Automatic stop announcements will be the first new feature on MBTA buses. This feature can be activated in a single bus, thereby providing immediate benefits without any fleet-wide modification or off-vehicle equipment. Using a global positioning system, an onboard computer will monitor the vehicle's position and trigger an automatic stop announcement when the bus reaches a specified location prior to each bus stop.
- Talking Stations – This step will incorporate electronic signage and the necessary communications equipment to trigger public address announcements (both audio and visual) at BRT stations. When a bus reaches a threshold distance from a station, there will be an automatic announcement about this. This talking station feature has been selected as the second improvement to be introduced because it requires minimal support services. It can be implemented in a few test stations long before the MBTA is prepared to implement this feature system-wide.
- Passenger Information Kiosks – BRT passenger information kiosks will be placed in major public facilities to provide customers with real-time information on expected arrival times of buses at nearby stops. These kiosks will allow passengers to wait indoors and then walk to the bus stop in time to catch the next bus. The kiosks may be introduced in small numbers to a thorough review by both customers and maintenance personnel before widespread application.
- CAD/AVL – After introducing the above passenger information features, the MBTA will implement a CAD/AVL system to monitor vehicle locations and schedule adherence. This information will provide dispatchers with the information they need to decide how best to respond to service interruptions or delay.

Charlotte-Mecklenburg County, North Carolina
Independence Boulevard Busway
The primary public transit service provider in Charlotte-Mecklenburg County is the Charlotte Area Transit System. This county contains five major transit corridors that focus on the city center. Major Investment Studies (MIS) were completed in 2002 relative to these transit

corridors and have developed locally preferred alternatives (LPA) in each corridor. Bus Rapid Transit was selected for the Independence Boulevard Busway Corridor, however, light rail transit is still under consideration for the preliminary engineering stage. The Independence Boulevard corridor is 2.1 miles in length was opened in 1998 after more than 25 years of expanding road capacity along this alignment. The two-way busway, which has no stations, is located on an unused HOV lane and is currently being extended another mile. It includes a queue jumper at the first outbound traffic signal that allows buses to bypass congestion. Reference (1) is the primary source of information for this summary.

The Independence Boulevard (US 74) Corridor has a long history of roadway and transit Development leading up to the selection of BRT as the LPA for this corridor:

- 1950s: Construction began on a major section of road. Initial plans called for two travel lanes each way plus on-street parking. In the mid-1950s, the plans for curbside parking were abandoned to allow three lanes in each direction.
- Mid-1960s: Roadway was re-striped to provide a seventh (left-turn) lane at intersections; trucks began using curb lanes because of the narrowness of the other lanes.
- Mid-1970s: Consultant report for state DOT recommended that Independence Boulevard be rebuilt as a freeway with a busway. The upgrade was necessary in view of continued traffic growth and the narrow lane widths (many were approximately 8 feet and the narrowest lanes were between 7 and 8 feet wide).
- 1987: North Carolina DOT upgraded Independence Boulevard from a signal-controlled arterial to a freeway, from I-277 in downtown Charlotte for about 3 miles. An expressway was created for an additional mile. Right-of-way acquisition began for the rest of the corridor. Daily traffic volumes had increased from about 45,000 in 1977 to 65,000 in 1985.
- 1987: Urban Mass Transportation Administration approved nearly $18 million to add a barrier-separated single reversible lane in the freeway median for HOV use, which was never placed in service.
- 1997: Phased approach to BRT was initiated. The busway demonstration project recommended a 3.9-mile busway with five stations. However, consensus regarding busway alignment and station locations was not reached, and no stations were built.
- 1998: When average daily traffic numbers (ADTs) approached 170,000 vehicles, express bus lanes were opened in the 2.9-mile [5-km] segment of unused High Occupancy Vehicle (HOV) lane.
- 2001: Construction began on the next mile of HOV lane.
- 2000-2002: Metropolitan Transit Commission (MTC) conducted MIS to study Independence Boulevard Corridor and assess transit alternatives including BRT and LRT. BRT was selected as LPA for this corridor though LRT will also be studied in preliminary engineering.

Proposed BRT features included retrofitting 3.9 miles of Independence Boulevard into a busway facility with five new stations with ITS technologies such as automated vehicle locators (AVL), automatic passenger counters (APC), and real-time information on the buses. CATS' long-range goal is to extend rapid transit for the entire 13.5-mile length of the corridor.

The Independence Boulevard Busway represents an innovative interim use of available road space. Originally planned as a whole package, disagreement about station locations forced a "phased deployment". This system shows how important it is to gain community support prior to implementation. Nevertheless, by not waiting for agreement about station location and proceeding with implementation without stations, CATS showed that even through such challenges, bus transit can still be implemented and can deliver benefits.

Cleveland, Ohio
Euclid Avenue BRT
The primary public transit service provider in the metropolitan Cleveland area is the Greater Cleveland Regional Transit Authority (GCRTA) with a fleet of over 700 buses on 98 routes and 108 rail vehicles on three rail lines. Reference (1) is the primary source of information for this summary.

Euclid Avenue is the primary public transit corridor serving the greater metropolitan Cleveland area. The plan to implement bus rapid transit along Euclid Avenue is comprised of a total package of improvements:

- Bus-only lanes
- Stations with provisions for off-vehicle fare collection
- Transit signal priority system
- Articulated multi-door buses
- Increased spacing of bus stops

Because Euclid Avenue is a sufficiently wide street with rights-of-way of 100 feet or more, this multi-attribute BRT development is possible. The plan has been generally accepted by stakeholders in the Cleveland central business district.

Eugene-Springfield, Oregon
Franklin Corridor BRT
Lane Transit District (LTD) is the transit service provider for Lane County, Oregon, which includes the communities of Eugene and Springfield -- the primary hubs for regional transit in the county. LTD conducted a Major Investment Study between 1992 and 1999 to examine transportation alternatives for the four-mile long corridor linking the central business districts of Eugene and Springfield and LTD selected bus rapid transit as its Locally Preferred Alternative for this corridor, the Franklin Corridor. Reference (1) is the primary source of information for this summary.

Approximately 60% of the route is designed with exclusive lanes for the 'EmX' vehicle that LTD has selected. The 'EmX' vehicle is specifically designed for BRT and is a 60-foot articulated bus using hybrid-electric propulsion. The vehicle has a modular composite body, stainless steel frame and a futuristic and rail-like appearance with wide doors on both sides and at-grade platform boarding. There will be off-board fare collection at each of the 10 stations with passenger amenities such as benches, shelters, ticket machines and passenger information displays. The remaining 40% of the route will be in mixed traffic and will utilize transit signal priority and queue jumpers to give the EmX vehicle priority through intersections. In addition, this corridor serves the University of Oregon and the Sacred Heart Medical Center, two of the biggest activity centers and transit ridership generators in the regional system.

Construction began in Spring 2004 and operation of the Franklin corridor is scheduled to commence in late 2006. LTD, the City of Eugene, the City of Springfield, and Lane County, will determine the sequence of future corridor deployment. LTD has selected incremental implementation for its long term – twenty years – goal of deploying BRT on all major regional corridors so that the system may be easily tailored to meet the specific transportation needs, and resource constraints, and opportunities within individual neighborhoods and transportation corridors. Implementation of BRT along the Franklin Corridor has been divided into planning segments for preliminary engineering and public input. The purpose of the public process is to educate residents and businesses about the BRT project and to gather their input on corridor issues and concerns. LTD has proceeded with the development of BRT along the Franklin corridor only with the approval of local municipalities. Such an approach can help establish initial success for BRT on a relatively short corridor, gain necessary public support, and help secure additional funding before proceeding with additional BRT investment.

Honolulu, Hawaii
City Express! Route A and B, and Country Express!
Bus rapid transit in the city and county of Honolulu may be traced back to 1998 and the beginning of a process – Oahu Trans 2K – to develop a vision for the future of transportation in this region of the island of Oahu. The Oahu Trans 2K process led to the development of the Islandwide Mobility Concept Plan and six major transportation projects for Oahu's future, one of which is the Bus Rapid Transit Project. Reference (1) is the primary source of information for this summary.

Honolulu's BRT system consists of three routes offering all day, limited stop service along three of the busiest bus corridors in Honolulu. The CityExpress! (A and B) and CountryExpress! routes utilize articulated buses with a unique rainbow identity. CityExpress! Route A was implemented first and in three phases:

- Phase I (March 1999): CityExpress! (Route A) began operating along the 6.6-mile primary urban corridor between the Kalihi Transit Center and the University of Hawaii. Headways during the week are 15 minutes and 20 minutes on Sundays and holidays.
- Phase II (August 1999): Service expanded an additional 6 miles to Pearlridge Center with six additional buses added to the fleet of BRT vehicles.
- Phase III (June 2000): Service was expanded 7 miles from Pearlridge to the community of Waipahu.

Average weekday ridership grew from 2,200 to over 6,000 between the initial rollout of Phase I through Phase II and so has been widely accepted by the community. The success of CityExpress! Route A resulted in establishing CityExpress! Route B in August 2000. The 7-mile corridor is between the Kalihi Transit Center and Waikiki and operates on 15- minute headways using 60-foot, low-floor, articulated buses.

In May 2000, a new limited-stop service, CountryExpress! Route C began again based on the success of Routes A and B. The service operates from the Waianae Coast to the second city of Kapolei and to downtown Honolulu. CountryExpress! operates daily from 5 AM to 10 PM with 30-minute headways and uses the new 60-foot, low-floor, articulated buses with 10 vehicles in the fleet.

Further improvements are being planned for the existing BRT lines:

- Transit signal priority on all three BRT routes
- Traveler information systems to display/announce bus arrival times
- GPS tracking system to enable bus riders to track buses on their personal computers
- Smart card technology for the payment of transit fares is being explored to reduce boarding time and to obtain more accurate ridership statistics and travel data to use in route planning.
- All-door boarding
- Marketing campaign to enhance the visibility of and ridership on the BRT routes.

Honolulu's BRT system is a representative example of phased development in terms of

- Extension of existing route
- Deployment of additional routes based on success of preceding route(s),
- Further service improvement of already existing lines through additional BRT elements such as signal priority, smart card technologies, advanced information technologies
- Total commitment resulting in long range plans for a system of dedicated BRT facilities.

The phased implementation of Routes A, B, and C was part of the city's and county's conversion of the upwind section of Oahu Island to a hub-and-spoke bus operation. The conversion resulted in establishing 10 community circulators, four new transit centers, and modifications to all existing service. Now Honolulu is actively pursuing the planning, engineering, and environmental studies for a system of dedicated BRT facilities.

Honolulu's example shows how BRT can be deployed in phases in time, place, service level and even in terms of planning. This example shows how both the community and the transit agency gained increasing confidence in BRT and were willing to commit more resources to their BRT system as they experienced its success.

Miami, Florida
South Miami-Dade Busway
The Miami-Dade Transit Agency (MDTA) is the primary transit service provider in Miami-Dade County, Florida. The Florida Department of Transportation, in conjunction with the MDTA, built the South Miami-Dade Busway ─ an 8.2-mile at-grade roadway for exclusive use by MDTA buses and emergency/security vehicles ─ that opened in February 1997. It was built mainly on abandoned rail rights-of-way at a cost of $59 million—slightly over $7 million per mile. There are 15 stations in each direction along the Busway approximately one-half mile apart. Six bus routes operate on all or part of the Busway; one of these—the Busway MAX—operates on an express schedule during peak periods. Reference (1) is the primary source of information for this summary.

Along the South Miami-Dade busway, there are two park-and-ride facilities that were built separately from the busway. The busway connects with the Dadeland South MetroRail station, which is a heavily used intermodal passenger transfer facility among the busway, the MetroRail, conventional MDTA bus lines, and automobiles. The station, which opened well before the South Miami-Dade Busway in 1984, needed infrastructural modifications to accommodate the busway when it opened in 1997.

Based on the market research, fiscal constraints, and planning guidelines, a three-part service plan was designed for the Busway and surrounding areas: (1) existing routes using US 1 were diverted to the Busway, (2) new Busway MAX and local bus service were initiated, and (3) neighborhood collector routes were established.

At the time the busway opened there were no plans for a phased deployment, i.e., it was implemented as a single total package of elements. However, currently, based on demand levels, the next phase of deployment for the South Miami-Dade Busway is being planned. It is an eleven-mile southern extension to the cities of Homestead and Florida City. It will include 12 additional stations with an estimated cost of $38 million. The extension will be divided into three segments: Northern Segment (5 miles), Central Segment (3.7 miles), and Southern Segment (2.7 miles). The Florida DOT is working on right-of-way acquisition. The MDTA is studying traffic signalization with the County Public Works Department and a consultant is preparing a Project Management Plan. The northern segment construction contract is currently out for bid. The extension will have three phases that demonstrates that BRT or an established busway can easily be extended in phases.

In addition service improvements along the existing Busway are being studied including alternatives to improve speeds along the busway and enhance safety where the busway crosses major street intersections focusing first on a single demonstration intersection. This will include the study of three alternatives: elevated structure, depressed by-pass, and at-grade warning devices and signals.

Ottawa, Ontario, Canada
The Transitway
OC Transpo, the Ottawa-Carleton Regional Transit Commission, is the public transportation service provider serving Ottawa, Ontario and neighboring municipalities. OC Transpo embraced bus-based rapid transit when, in the 1970s, it decided to upgrade its transit system based on a regional plan that gave priority to rapid transit over road widening and new road construction in an environment that supported a multi-centered urban structure with the Ottawa central business district (CBD) being the dominant commercial, employment, and cultural center of the region circled by two lower tiers of urban centers. Outside these centers, market-driven patterns of development would be allowed and rapid transit would be the primary means of achieving this form in which the development of the stations in town centers was a high priority "…. to ensure that the urban form of these town centers will incorporate the Transitway as an integral part, rather than as an after-thought" (1).

The most cost-effective strategy recommended was for the construction of a system of separate rights-of-way rapid transit in the corridors leading up to the central business district (CBD) with at-grade running ways on priority rights-of-way through the CBD, henceforth called transitways. Busways were considered the least costly option for these transitways. A bus-based system could be built for half the capital costs of light-rail transit and would be about 20 percent cheaper to operate. The selection of diesel bus technology was also based on its flexibility. Buses could circulate through the suburbs, pick up riders, and then enter the Transitway for a fast run downtown, whereas a rail-based system would have required one or more transfers.

Ottawa made the decision to use the bus as the backbone of the city's transit system, and in 1973 introduced approximately 6.8 miles of bus lanes. By 1983, the first sections of the Transitway (exclusive busways) were opened providing buses with exclusive, grade-separated right-of-way. In 1996, the initial 19.2 miles that were approved in 1978 were completed spanning two primary trunk lines. In 1998, a new image and color was introduced along with low-floor buses. In 2000, construction began on the third trunk line as well as extensions to the two existing trunk lines. Articulated buses are introduced in 2001. Today, the 37-mile system, comprised of three trunk-line routes, utilizes 17 miles of bus-only exclusive right-of-way with most of the remaining distance on reserved freeway or arterial lanes (priority lanes and mixed traffic). There are 36 stations with five major intermodal stops and four park-and-ride facilities. It has been extremely successful, making nearly 200,000 trips per day, and capable of carrying 10,000 riders per hour in each direction.

In many ways, the Transitway has conventional transit system attributes:

- Conventional bus length (standard and articulated)
- No wide doors
- Two right hand side doors and no left-hand side entry, i.e., no median entry
- No automatic stop: passengers must inform driver of their desire to stop and exit
- Entrance via front door depends on time-of-day and day-of-week, e.g. weekends
- On-vehicle fare collection (or show a paid-for-in-advance monthly fare card)
- Only on-board signage is a sign indicating the next stop has been requested and "EXIT AT REAR" sign.
- Right-of-way allows mixing with non-bus vehicles in certain locations, e.g. in the Ottawa CBD.
- Ordinary bus stops/shelters exist along the route though are not indicated on the published Web site route map.

The Transitway, however, has features that make it special. In the outlying areas as it gets away from the more urbanized areas, the Transitway's right-of-way is an exclusive bus lane that is at- and above-grade depending on location usually with one lane per direction. At each station, the right-of-way expands to two lanes per direction. On the exclusive busway speed limits vary between approximately 35 and 50 miles per hour and within the station area, the speed limit is approximately 30 miles per hour, unless a stop is required for passenger drop-off or pickup. Moreover, at some locations, the exclusive right-of-way is directionally separated by barrier or a grassy median. In a few locations, the bus uses the freeway for short distances (1-2 miles) in an exclusive bus lane. This lane is the freeway's right-most lane that is an exit-only lane for use only by Transitway buses. It is separated by means of a virtual barrier with diamond symbols painted on the bus lane. Some of the Transitway's stations have similarities to rapid rail stations, not in the sense that they are underground (in fact, there is only one tunnel station on the Transitway's route), but that they are infrastructurally extensive. For example, some of these stations are adjacent to commercial office development and are linked together via enclosed walkway bridges. At one location, the Transitway has a stop immediately outside a major department store that is part of a suburban mall. The extensively built stations are fully enclosed to accommodate Ottawa's winter weather with multiple stops for entry onto and exit from buses. Also, bus routes for lines other than for the two Transitway lines converge at several of the Transitway's stations. In addition to the Transitway connecting with Ottawa's International Airport, it also connects with train service (VIARAIL/RAIL CANADA) at Ottawa's train station with an enclosed walkway bridge linking the two stations.

One of the more striking features of BRT transit planning in Ottawa has been the emphasis on an unconventional coverage of the system, rather than investing heavily in short sections of mass transit in the more congested central area and continue with the more traditional 'inside-out' strategy, an 'outside-in' approach was taken that allowed initially for a broader system to be implemented and more exclusive right-of-way to be built with available funding than otherwise. As a result, initial funding has been devoted to extending the system to capture suburban markets while relying on much lower cost transit priority measures to increase capacity and reliability within the CBD. This alternative approach has proved to be cost-effective in attracting ridership.

The Ottawa Transitway system is the result of deliberate long term planning that gave priority to transit development over highway expansion. Planning emphasized coverage of the system first. Therefore, first the busways were built all the way out to the suburban communities as well as outlying stations. Later, stations closer to the downtown were added.

The Transitway deployment phases were determined by the long-range plan and basically driven by location of high demand (station location).

Pittsburgh, Pennsylvania
South, East and West Busways
The Port Authority of Allegheny County is the public transportation service provider for the greater Pittsburgh metropolitan area. The Port Authority has three busways: South Busway, East Busway, and West Busway for a total of 18.4 miles of busways. The busways serve about 20% of Allegheny County's daily transit riders, link south, east and west communities with the city center, and result in substantial savings in passenger travel times. Reference (1) is the primary source of information for this summary.

The South Busway is 4.3 miles long and is the Port Authority's first exclusive bus roadway, as it opened for service in December 1977. Approximately 16 express and local bus routes serve the South Busway with eight stops located along this corridor. The South Busway is credited with average weekday ridership of 13,000 and yearly ridership close to 4 million.

The East Busway is a 9.1-mile, two-lane bus-only roadway constructed adjacent to an operating railroad right-of-way. The East Busway opened for revenue service in February 1983 initially with 6.8 miles of busway that were extended another 2.3 miles in 2003. This busway serves Downtown Pittsburgh, several East End communities and the eastern suburbs of Allegheny County with approximately 36 routes providing express and local bus service. There are 10 busway stations spaced approximately one mile apart that provide drop off and pick up points as well as transfers to and from local bus service. Average weekday ridership is nearly 30,000. Yearly ridership exceeds 7.5 million.

The West Busway is the third and newest of the Port Authority's busways that opened in September 2000. The West Busway is a five mile exclusive bus roadway with six stations spaced approximately one mile apart providing service between Downtown Pittsburgh and several communities west of Downtown Pittsburgh. Weekly ridership averages approximately 40,000 passengers. Fourteen routes run on the busway with express and 'all-stop' local bus service, which follows an abandoned rail right-of-way and uses a rehabilitated rail tunnel.

There is also through service between the East and West Busways.

In addition to the busways, the North Hills Expressway HOV lanes enable express buses traveling between downtown Pittsburgh and the North Hills to bypass congestion. Three free park-and-ride lots are served by express buses. There is also a planned reversible lane for buses and car pools in the Wabash Tunnel under the South Hills. Bus service within and through the Golden Triangle is provided over city streets, often in contra-flow bus lanes.

The Pittsburgh Busways are "state-of-the-art" facilities. They were not inexpensive to build. Each was built as one complete package, part of an overall system.

Seattle, W
METRO Bus Tunnel
Metro Transit is the public transportation service provider for King County, Washington that includes the Seattle metropolitan area. In 1990 Metro Transit opened its 1.3 mile/5 station bus tunnel under the Seattle downtown area. One factor that significantly influenced Metro's decision to consider only bus alternatives during the project planning period was the federal government's "no new rail starts" position and the tunnel was built as a single total package for bus operation. The second phase use of the tunnel to include light rail transit jointly used with buses was being planned for as well. Reference (1) is the primary source of information for this summary.

The buses, which are dual-powered bus electric/diesel vehicles, run on overhead wires through the tunnel whereas outside the tunnel buses switch to diesel power to run on the streets and highways. Meanwhile streets of Seattle have a mix of true trolley bus routes and traditional bus routes. Light rail transit will be built in the downtown Seattle area and beginning in September 2005, the bus tunnel has been closed to convert the tunnel for joint bus/LRT use.

As the tunnel serves as an additional street through downtown Seattle, the tunnel helps relieve traffic and pedestrian bottlenecks aboveground by removing many buses and bus riders from streets and sidewalks. To reduce noise and diesel fumes in the tunnel, Metro ordered 236 special dual-power buses. These buses use diesel power on the streets and highways, and switch to electric power to go through the tunnel. Tunnel buses go through downtown almost three times faster than buses do on surface streets. With fewer buses on surface streets, all Metro bus trips though downtown are faster and safer whether or not the buses use the tunnel. About 40 percent of all rush-hour bus trips through downtown Seattle use the tunnel. Security personnel patrol the tunnel. Metro also monitors station and tunnel areas with a closed-circuit television system. Each station has information and emergency telephones tied directly to the Metro tunnel communications center. The tunnel and stations have automatic fire-detection and suppression systems. Tunnel hours are 5 a.m. to 7 p.m. on weekdays and 10 a.m. to 6 p.m. on Saturdays. The tunnel is closed on Sundays and holidays. When it is closed, routes operate in both directions along Third Avenue between Yesler Way and Olive Way. Southbound buses travel west along Stewart Street before turning south on Third Avenue. Currently, 21 Metro Transit bus lines use the tunnel as part of their routes. Most entrances have elevators. All tunnel buses are equipped with wheelchair lifts.

Vancouver, BC
"B" Lines Bus Rapid Transit
Greater Vancouver Transit Authority (TransLink)

#99-B, #98-B, #97-B Lines

The integration of land use and transportation has been a cornerstone of regional planning policy since the later 1960s when the region rejected a freeway network plan. The Greater Vancouver Regional District (GVRD) sets land use and transportation policy. Its "Livable Region Strategy" lays out a blueprint for future development of the region that includes a transit oriented transportation system. The strategy creates more compact communities that are anchored by regional and municipal town centers and are supported by high-quality transit links. Reference (1) is the primary source of information for this summary.

Transportation investment is seen as a tool for encouraging desired land use patterns. The strategy identifies five corridors for new Intermediate Capacity Transit System (ICTS) lines to be developed over the next 25 years. More intensive urban development in these key growth corridors will support the region's land use vision. BRT is viewed as a stepping stone to a full ICTS, which is defined as segregated busway, light rail transit, or Automated Rapid Transit that can carry 10,000 passengers per hour per direction.

Vancouver is looking at BRT in medium density corridors where investment in ICTS is not warranted because of costs and ridership. BRT is targeted at corridors that typically carry between 1,000 and 3,000 passengers per hour per direction. However, rail transit comes with disproportionately higher costs per passenger. From an economic standpoint, carrying passengers on ICTS is at least four to five times more expensive than BRT. Also, few corridors in the Vancouver region have or will have the densities and ridership potential to support heavy investment in ICTS development.

Bus rapid transit was developed in three corridors as an early-action means of improving service.

1. The #99 B-Line (Broadway-Lougheed) bus service between the University of British Columbia and New Westminster began service in 1996.
2. The #98 B-Line BRT service in the corridor between downtown Vancouver and Richmond started in August 2001.
3. The #97-B-Line BRT in the Coquitam-Lougheed corridor opened in 2002.

These services are an outgrowth of more than three decades of rapid transit planning.

#99 B-Line – Broadway-Lougheed
"The #99 B-Line (Broadway-Lougheed) is one of the heaviest bus routes in Vancouver and complements the Route 9 Trolley Bus that operates east/west along Broadway as a cross-town route. The #99 B-Line, the first Rapid Bus service in Vancouver, provides an "overlay" service that only serves major destination points along a 27-km (17-mile) BRT route; it has 14 stops – one every 1.9 km (0.8 miles). This stop spacing is about three times the spacing provided on the existing route."

"A special B-Line logo was applied to route maps, timetables, bus stop signs, and information pieces to provide a distinct image of the service to customers. For the first two years of operation, a mixture of standard and articulated buses displaying the systemwide paint scheme was used. In September 1998, a new fleet of 21 low-floor articulated buses with a distinctive B-Line paint scheme was deployed. Following this change, ridership increased 20 percent over 1997 levels. Five more articulated buses were subsequently added."

#98 B-Line – Richmond
"The Richmond-Vancouver corridor includes downtown Vancouver, Richmond City Center, and Vancouver International Airport. Growth in these areas, located to the south of the downtown, has surpassed initial projections. A rapid transit link between Richmond and Vancouver has been part of regional planning policy since the 1970s. A light rail line along the former British Columbia Electric's Arbutus right-of-way between downtown and Richmond was studied in the 1970s. The corridor has been identified for ICTS (i.e., SkyBus) since the mid-1970s. Bus rapid transit was perceived as a way of meeting the demands in the corridor because it replicates many features of ICTS. The public's popularity and positive response to the #99 B-Line service gave further impetus for BRT development." (1)

"The 98 B-Line service is most comprehensive in its service quality, and is the prototype of future B-Line services in the region."(*2*) "The #98 B-Line route between Richmond and Vancouver is a key component of Vancouver's TransLink Strategic Transportation Plan. The line opened on August 7, 2001, after a 4 1/2 month transit strike. It replaced a confusing array of bus routes with a simple, direct, and frequent service. It combines limited-stop, high-frequency articulated bus service with several transit priority measures including dedicated curbside and median bus lanes, queue jumpers, and transit signal priority. In addition, the route uses an automated vehicle location system with real-time bus information provided at bus stops along the route." (1)

"The 98 B-Line service was implemented in stages, commencing in November, 2000. Full implementation involved an expenditure of approximately $52 million for vehicles, on-board transit management system, stations, busway, land, and traveler information systems, as well as a share of the new maintenance facility in Richmond. Full service commenced in the summer, 2001.

There were several phases in the implementation of the 98 B-Line:

- Preliminary Design (1997/98): Evaluated alternative routes and selected the preferred route and station locations.
- Detailed Design (1999/2000): Refined the route location and station locations, designed road and busway improvements, shelters and stations, traffic signal priority system and traveler information system.
- Construction (2000/01): Acquired land, constructed road and busway improvements, constructed bus shelters and stations, acquired vehicles, implemented traffic signal priority and real-time traveler information systems.
- Training and Service Commencement: Training commenced in December 2000, was delayed for 4 months due to a transit strike during the period April – July, 2001, and service commenced in August 2001." (*2*)

There continues to be strong interest in developing a rail rapid transit service in the corridor, given the growth rates and the long lead time required to develop, finance, and construct such a system. In the mean time the #98 B-Line BRT operates successfully.

#97 B-Line – Coquitam Center

"The #97 B-Line, which became operational in 2002, is a bus-based, on-road extension to Coquitam Center from the new SkyTrain. Extension of the Millennium SkyTrain Line to Coquitam City Center is a long-term priority because its $730 million (CAN) cost precludes it in the near to medium term. The proposed BRT line will provide the interim access until the rail line is built.

The 10-km (6-mile) route has 18 stops. Service frequency is set at 10 minutes during peaks and midday and 15 minutes during the evening. Weekday ridership is estimated at 6,000, and fare box cost recovery at 56 percent.

TransLink is examining new ways in which priority may be introduced into the corridor. These include transit signal priority and sections of dedicated curbside bus lanes or median busway. The more suburban setting of this route suggests that curb lanes may be more practical than in the urban areas where development is more mature, and bus lanes are difficult to accommodate without impacting local businesses." (*1*)

The B-lines are the results of integrated land use and transportation planning. BRT has its place clearly defined within the transportation system.

The #99 B-Line (Broadway-Lougheed) began service in 1996. It operated with a mixture of standard and articulated buses displaying the system-wide paint scheme. "In September 1998, a new fleet of 21 low-floor articulated buses with a distinctive B-Line paint scheme was deployed. Following this change, ridership increased 20 percent over 1997 levels. Five more articulated buses were subsequently added."

The #99 B-Line is an example of BRT's flexibility. It can be deployed without all elements being in place. This will deliver benefits earlier to the community, in this case, two years earlier. In addition, this example shows that adding the very visible element, designated vehicles, will improve system's perception and ridership.

The #98 B-Line seems to have been implemented as one complete package. There were a 4 and a half month interruption in its implementation due to a transit strike. However, this was certainly not a planned phasing of deployment. There is continuous interest to implement a rail line on this corridor. If that happens, BRT will be the first phase of the full ICTS development.

The #97 B-Line exists because the rail line proposed on its corridor is too expensive to build. It seems to have been implemented as one package with further improvements in plan. Currently #97 B-Line operates on-road, that is, in mixed traffic. However, TransLink is examining new ways of reducing travel time through additional priority treatment to buses by signal priority and/or sections of dedicated curbside bus lanes or median busway. These plans could be viewed as the second phase of this BRT line. The final stage would be the proposed rail line that would extend the Millennium SkyTrain Line. It was certainly the prohibitive cost of the SkyTrain extension that forced TransLink to consider BRT as a first stage of the rapid transit system on the corridor. We do not have sufficient information to decipher why signal priority was not implemented from the beginning.

This report describes the deployment of a Bus Rapid Transit (BRT) system to enhance bus operations and improve customer service in the Greater Vancouver area of British Columbia, Canada. In August 2001, BRT route #98 B-Line was introduced to connect the city of Richmond with Vancouver. The BRT service includes several ITS components including Automated Vehicle Location (AVL) technology, transit signal priority systems, onboard voice and digital announcements of next stop information, and real time bus arrival time information using digital countdown signs at bus stops. In addition, other non-ITS components were deployed including dedicated curbside bus lanes, queue jumper lanes, median busways, and platform stations at signalized intersections.

The AVL technology deployed uses a global positioning system (GPS) to track vehicle location. On-board computers calculate the location of each bus and send data to a central control center where each bus's location is mapped on a computer screen using flag-shaped icons. Green flags represent buses ahead of schedule and red flags represent buses behind schedule. Transit management personnel monitor bus progress on each route and advise operators of schedule deviations. Mobile Data Terminals (MDT) facilitate voice and data communications between drivers and the transit control center and allow bus drivers to select unique messages to communicate with passengers concerning route or schedule adjustments. In addition, if a bus is behind schedule, the AVL system automatically links to an integrated automated signal control system and requests green signal extensions, or advanced green signals at intersections pre-authorized to provide conditional priority in each jurisdiction. AVL is also installed on two supervisor cars, to allow the transit control center to determine the location of supervisors relative to any buses that may need assistance.

The #98 B-Line investment included the acquisition of 25 business properties and the development of five stations spaced approximately 300-400 meters apart on a 2.5 kilometer section of median busway on No. 3 Road in the city of Richmond. The service operates 22 hours per day, seven days per week, and uses 22 low floor articulated buses out of a fleet of 28 vehicles. The route uses 18 bus stops and shelters and services approximately 18,000 passengers per day.

Overall, the capital cost for all ITS and non-ITS system components totaled $44.2 million Canadian (CAD) (2001). The table below, excerpted from the report, details the ITS capital cost components of the project. The report contains a cost breakdown of the non-ITS components.

2.5.1.2 Europe

None of the three European BRT systems is described in sufficient detail in Reference (1) to reveal their deployment history and the reasons for it in any significant detail. However, some of their designs suggest a phased implementation.

Leeds, UK
The guided bus system, referred to as the Superbus, includes five primary bus routes that follow a common alignment between the Northern suburbs and the Central Business District (CBD) of Leeds. The system has been operational since 1995. The reported reasons for implementing the guided bus systems include the following: (1) in certain locations, the narrow width needed for guideways can save space as compared with providing extra traffic lanes, and (2) the guideways are self enforcing as queue bypasses, thereby ensuring unimpaired passage for buses.

The system uses segregated guideways with mechanical guidance at strategic locations. Exclusive continuous busway tracks are not provided for the guided buses over the full length of either corridor. The common alignment has four sections of guideway totaling 1.5 kilometers (0.9 miles). Other sections of the routes are provided with conventional, with-flow, bus priority lanes and bus priority at traffic signals. Sections of guided busway track operate for 24 hours. Bus priority was considered a way to provide buses a counterweight against traffic congestion.

The guideways have been constructed adjacent to existing roadways leading up to intersections where queues develop. The guideways extend beyond the average queue length of approximately 800 meters (0.5 mile), thereby enabling buses to bypass the congested traffic. As the bus moves along the guideway, a detector linked to the traffic signal gives buses priority at the intersection. The unit cost of construction of the infrastructure of the Leeds one-way guideways within an existing highway including track, physical guidance, traffic signals, footways, road works and landscaping, was, in US currency, approximately $4,500 per bus.

The system in Leeds is a low cost BRT system that is a combination of bus operations in mixed traffic and along a guided busway. It is a clear example of the flexibility of BRT in terms of infrastructure. While there is a lack of information providing details about the deployment of the operating system, such system can be implemented one segment at a time, one queue jumper at a time even during service. Alternatively it can be implemented as one package as is expected to occur with the new East Leeds Quality Bus Initiative Scheme.

Runcorn, UK
The system in Runcorn was likely implemented as one package based on the following attributes:

The busway comprises an exclusive bus track that serves residential and industrial areas of the town and intersects the town center. Housing and employment locations were distributed such that 90% of the working population was within a 500-meter or 5- minute walk of the nearest bus stop. The Runcorn busway is purpose-built and integrated busways with land use development. However, the experience was not directly applicable to *existing* towns; however, as the busway plan was the core element of a planned *new* town and was not introduced into an existing urban area.

Rouen, France
TEAR Optically Guided Bus

A three-route bus rapid transit (BRT) system was placed in service in 2001. Civis-guided buses use optically guided scanners in curb or median lanes to assure proper positioning at the station. Neighborhood revitalization and urban design features were integrated with system development. The initial bus fleet included 38 guided articulated vehicles (essentially guided conventional buses) and one Irisbus Civis diesel electric articulated vehicle. These 38 buses will be replaced by 56 additional diesel electric Irisbus Civis guided articulated buses.

The system in Rouen, France uses the Civis bus. System operation started before the acquisition of all Civis buses. No reason was given. However, since the Civis is such a new vehicle, it could be that the vehicles were still in production. Or simply budgetary considerations pushed the purchase of the vehicles to a later time. However, no more information on deployment was given in TCRP Report 90. Nevertheless, Rouen's example shows that BRT can be put into operation even if not all elements are ready or available at first day of operation.

2.5.1.3 Australia

Adelaide, Australia
O-Bahn
During the 1960s, transportation planning in Adelaide mirrored North American perspectives. When the region was rapidly suburbanizing, major freeways were proposed to handle traffic growth, and public officials began preserving rights-of-way. However, by the 1970s, growing concerns over environmental quality and energy consumption led to public backlash, and only one freeway was actually built between the central city's edge and the hills to the east. The OBahn corridor was designated as a freeway in 1960.

An extensive review of Adelaide's transport options in the 1970s led to abandoning the idea of additional freeways in the city (3). Instead, a decision was reached to develop rapid transit to service the rapidly growing northeastern suburbs, the only corridor not serviced by a suburban rail line.

After extensive study, officials decided to build a new light rail transit (LRT) line in 1978. As work progressed, the projected costs of placing the LRT underground in the city center proved prohibitive.

The O-Bahn was proposed with a change of governments in 1979. In 1981 a decision was made to build a high-speed busway using the O-Bahn technology. Detailed design commenced in 1980, and construction began in 1982. The first 6 kilometers were opened in 1986 between the city and Paradise, and the extension was opened in 1989.

Adelaide's O-Bahn Northeast Busway extends 12 kilometers from the central area to the Northeastern suburbs. Buses from 18 different routes wind through the northeast suburbs before entering the guideway at one of two access stations. With steering completely controlled by the guideway, buses reach speeds of up to 100 kilometers per hour (62 mph) on the fully grade-separated facility. They stop at a third station, Klemzig if there is customer demand. On reaching the outer edge of the CBD, vehicles leave the guideway and travel the remaining 3 kilometers to the core stations on city streets, just like regular buses. Approximately 1,000 park-and-ride spaces are provided at the two main stations. A linear park and bicycle way parallel the busway. This route is "designed to allow for future electrification", which would be a change in bus propulsion, not a change from buses to light rail.

Adelaide's O-Bahn is a result of city planning, budget constraint and an extension. Yet another good example of that bus service can be expanded easily. The guideway does not have to be continuously built and operated and opened in one step. It can be built incrementally. Also, this system exemplifies that buses can leave the trunk route and operate as collector/feeder service. Furthermore, in case of a breakdown, buses can leave the guideway and get around the disabled vehicle on regular streets.

Since its opening, articulated buses were available as demand grew. There is a plan to convert buses from diesel to CNG propulsion. These continuous improvements show that BRT can be easily updated as ridership demands or as technology become available.

Brisbane, Australia
South East Busway
Brisbane "has implemented 23 bus priority routes including the Woolloongabba and City bus tunnels with dedicated rights-of-way, 2 high occupancy vehicle (HOV) transit lanes, 19 bus-only lanes, and the South East Busway. The Inner Northern Busway is under development."

The South East Queensland Planning Framework involves land use and growth management that provide the context for a 25-year transport plan, a 7-year transport action plan, and a 3-year transport program. The goal by 2011 is to accommodate about 10 percent of the 11.8 million person trips made by public transport as compared with 7 percent at present. Proposals include selective increases in road capacity, land use controls and demand management, and public transport improvements. Transit proposals and actions include rail extensions, a busway network, bus priorities, transit centers, and bikeways. Two busways are in the plan—a South East Busway to Eight Mile Plains and the Inner Northern Busway. The South East Busway, progressively opened between September 2000 and the middle of 2001, is the result of 5 years of planning design, construction, and community liaison.

“The 17-kilometer [10.5-mile] South East Busway extends from the Brisbane Central Business District to the southern suburbs. The busway includes surface and tunnel operations on exclusive rights-of-way. The $400 million busway includes 10 attractively designed stations and a bus operations center that employs modern Intelligent Transportation System (ITS) technology. It traverses a highly developed urban area and a constrained corridor. Priority lanes connect with the southern busway terminus. Over half of Brisbane Transport bus routes use some part of the busway.

The South East Busway is the result of land use and growth management and a desire to increase transit usage. It is part of the system wide plan that includes rail extensions, a busway network, bus priorities, transit centers, and bikeways. The TCRP Report 90 does not say much about this system, only that it was progressively opened between September 2000 and May 2001. It does not detail this progression. Additional research into the system deployment is needed.

Sydney, Australia
Liverpool – Parramatta BRT

This BRT route is the first corridor of a whole BRT system. Otherwise, it is deployed as one total package. It was supposed to open in 2003. Its entire EIS is available at the following website: http://www.rta.nsw.gov.au/constructionmaintenance/downloads/envirliver_dl1.html

2.5.1.4 South America

Bogota, Columbia
TransMilenio BRT
TransMilenio is based on the successful experiences of the Brazilian cities of Curitiba, Porto Alegre, as well as Quito, Ecuador. The TransMilenio median busway system was built over a 3-year period and placed in revenue service in December 2000. Reference (1) is the primary source of information for this summary.

TransMilenio is a public/private system that is designed for operation by private contractors who are under government oversight. System implementation required detailed technical, legal, and financial design; creation of a new public entity in charge of system planning, development, and control; overcoming resistance to change from traditional operators and small bus owners; development of the infrastructure; contracting and starting up the operation; and earmarking local and national funds for system expansion.

Based on Information in TCRP Report 90 it seems to have been implemented as one package.

Quito, Ecuador
Quito Trolebus
Project planning for an integrated public transport system, of which the *Quito Trolebus* scheme along the major north-south corridor forms the key component, was commenced in 1990 and became operational in 1996. The *Quito Trolebus* is part of a trunk-and-feeder bus system with trunk line services provided by trolleybuses operating on a busway that is mainly segregated from other traffic. The trunk line can be accessed directly by passengers at on-line stops or by feeder buses with interchange at purpose-built terminals or at a number of trunk line stops. The *Quito Trolebus* operates along the north-south transport spine of the city. The route has terminals at both ends where feeder bus lines converge to serve the *Trolebus*. Buses are connected at several sections of the corridor; the route includes three overlapping service patterns. The busway comprises two sections of which a bus-only track runs for 11.2 km (7 miles) with one lane per direction. The busway track is discontinued through the historical center of the city where conventional bus lanes are used. The trolleybus busway first opened in 1995 and was extended in 1996 and 2000.

The Bus station/stop configuration is similar to that in Curitiba. Passengers pay at entry to stops, not on buses. Buses are specially built with high doors, and thus, stop platforms are raised to bus floor height with bus doors coordinated with stop doors. Bus doors have fold-down steps that deploy when a bus stops; therefore level and gap-free passenger boarding/alighting is provided.

The costs of the initial 11.2-km busway section (data available), including articulated trolleybuses, was $57.6 million in U.S. dollars (US) in 1996 and costs included (1) vehicles and infrastructure ($US 46.3 million), (2) terminals and stops ($US 7.0 million), (3) traffic signals ($US 2.3 million), and (4) a ticket system –($US 2.0 million).

In many cities in the past, busway implementation has not been achieved because institutional responsibilities were fragmented. For example, in a conventional city, a busway can involve the traffic-planning department, the transport-planning department, the highway department, the bus licensing authority, various bus operators, traffic police, and others. To realize the Quito scheme, the mayor made fundamental changes to the city's transport-planning structure and created a *single* agency, the Unidad de Planificación y Gestión del Transporte (UPGT), with a clear mandate and adequate powers to take control of public transport. This was achieved with strong political backing that was key to the scheme's realization and success.

Based on information in TCRP Report 90 it appears that the original section of the *Quito Trolebus* was deployed and opened for service as a single package in 1995. This original section was extended twice, in 1996 and again in 2000. Another important feature of the system in terms of deployment is that the busway track is discontinued through the historical center of the city where conventional bus lanes are used.

São Paulo, Brazil
9 De Julho Busway
São Paulo has been a world leader in seeking innovative physical means to assist bus operations and innovative bus management (notably the bus platoon-train system). The city adopted a trunk-feeder bus service concept, using bus-only lanes placed in central median reservations. The Avenida 9 de Julho/Santo Amaro Busway extends 11 kilometers (7 miles) along a radial corridor to the southwest of the city center. The busway comprises a reserved track that is discontinuous for two short sections: the first section is through a tunnel where there is inadequate width for the full busway/road cross-section and the second section is through an underpass.

The busway is located in the center of the road. There is one bus lane in each direction and double-width tracks at bus stops that permit overtaking of stopped buses by through buses. Bus stops are spaced at about 600 meters (200 feet) and contain island platforms; generally, these are accessed by passengers at mid-block traffic signals. Few left turns by other traffic are permitted across the busway; such turns are generally accommodated by turns at side roads. Bus flows are high, and while some buses are electric trolleybuses, most are diesel powered. Thus, emissions and resultant air pollution are problems.

It is likely, based on the system description that the system was deployed as a package. From deployment point of view this system is interesting because (like the *Quito Trolebus*) the busway discontinuous for two short sections: "the first section is through a tunnel where there is inadequate width for the full busway/road cross-section and the second section is through an underpass." Such deployment of LRT would not be possible.

Curitiba, Brazil
Curitiba's bus system's development is a unique experience. It was developed as an integral part of an overall master plan "whose basic objectives included radial expansion of the city along five corridors (structural axes), integrating land use and transport, and protecting the traditional city center." As a result, transit is not a response to the city's transportation problems but a driving force in the development of the city. Therefore, the deployment features of the Curitiba system are unlikely to be applicable elsewhere.

Summaries of these case-study evaluations that focus on deployment are depicted in Table 12.

TABLE 12: Summary Of Case Study Evaluations

BRT SYSTEMS	SINGLE PACKAGE OR INCREMENTALLY PHASED	DEPLOYMENT DETAILS	COMMENTS
NORTH AMERICA			
Boston, MA Silver Line	Phased in terms of roadways sections, BRT elements, technology	3 sections, incremental technical development, new vehicles at system integration	
Charlotte, NC Independence Blvd Busway	Phased in terms of BRT elements, one extension	Interim use of HOV lane, no stations,	Needs agreement and community support
Cleveland, OH Euclid Ave	Package		Wide ROW available, community support secured
Eugene-Springfield, OR East-West Pilot BRT	Phased in terms of running way sections, but sections are complete packages	2 phases, second phase has 2 sections, cautious approach to secure public support	2nd phase needs funding
Honolulu, Hawaii City Express! Route A and B, and Country Express!	Phased in terms of: • Extension of existing route • Additional corridor • Additional ITS tech. • Development of long range system wide commitment	Increasing community support and agency confidence lead to additional lines, increasing investment in service level and finally to long-range BRT system	
Los Angeles, CA Metro Rapid Bus/Wilshire BRT	Phased in terms of BRT elements	Within phases jurisdictional differences, demonstration sections,	Clear planning of phases

BRT Systems	Single Package or Incrementally Phased	Deployment Details	Comments
Miami, Fl South Miami-Dade Busway	Original package, one extension,	Extension will have three phases, service improvement to old system through technology	Originally could not afford LRT
Ottawa, Canada Transitway system	Phased *outside-in* approach	First entire length of running way to connect outlying areas, second stations closer to city center	Result of long term land use planning
Pittsburgh, PA South, East and West Busways	Package, one of them extended	Extension is one package	"state-of-the-art" facilities
Seattle, W METRO Bus Tunnel	Package, long range plan for conversion to rail	Being converted to mixed use bus and rail tunnel	Controversial whether conversion was necessary
Vancouver, BC, Canada #99-B, #98-B, #97-B Lines	#99-B: Phased: BRT elements #98-B: package #97-B: Phased: 3 phases	#99-B: vehicles added 2yrs later #98-B: interrupted by strike #97-B: 1: original in mixed traffic 2: travel time reduction 3: extension of Skytrain	Integrated land use and transportation policy; clear definition of BRT's place in system,

BRT Systems	**Single Package or Incrementally Phased**	**Deployment details**	**Comments**
Australia			
Adelaide, Australia O-Bahn	Package, articulated buses were added as demand required them; one extension,	Plan to upgrade vehicle propulsion	Extension due to new population center
Brisbane, Australia South East Busway	"Progressively opened"		No details
Europe			
Leeds, UK	Can be implemented as a package or phased in one queue jump at a time		Infrastructure flexibility: Mixed traffic and guided busway
Runcorn, UK	Package		Built as part of a new city
Rouen, France TEAR Optically Guided Bus	Phased in terms of BRT elements	System opened before Civis fleet was available	
South America			
Bogota, Columbia TransMilenio BRT	Package		Not enough detail
Quito, Ecuador *Quito Trolebus*	Package, two extensions		Infrastructure flexibility: busway track is discontinued through city center
São Paulo, Brazil 9 DE JULHO BUSWAY	Package		Infrastructure flexibility: busway discontinuous for two sections

2.5.2 Analysis of Phased Deployment of Bus Rapid Transit Systems

Based on the assessment of the BRT systems depicted in Table 12, numerous factors have been identified that can help understand the phased-in deployment process for a bus rapid transit system.

- **Urban and land use planning** determines the big picture. Integrated planning of land use and transportation or "transit first" policies result in different deployment phases from the "response to congestion" approach. Long-range land use planning influenced the deployment stages of Ottawa's BRT system. Integrated transit planning in Vancouver clearly defined the place of BRT in the multi-modal transit system, thus making BRT either a final transit mode on a corridor or the first phase toward an Intermediate Capacity Transit System. In Eugene-Springfield the middle, most traveled, section will be deployed as final stage in Phase I and in Phase two the route will be extended on both sides.

- **Local urban environment** These BRT systems are built in already mature cities. Any number of local circumstances can effect their deployment.
  - In Boston the construction of the Silver Line was coordinated with other **ongoing projects**.
  - **Demand characteristics** may determine which station is deployed first (Ottawa)
  - **Already existing infrastructure** can determine/create deployment phases, such as the rebuilding of an old tunnel in Silver Line Phase 3 in Boston, MA.

- **Community support** is essential. It can influence what can be done. For example, lack of agreement resulted in no stations in Charlotte. Community support is essential to obtaining curbside lane. Confidence of the community and the transit agency in BRT can be built up through phases as Honolulu's example shows.

- **Budget constraints** size the system and can force phased deployment (like acquiring buses later, such as in Rouen, France)

- **Passenger demand** can trigger an extension (Adelaide, Australia)

- **Institutional constraints, jurisdictional differences** can dictate what BRT element can be deployed and when. Two jurisdictions did not allow signal priority in parts of LA's Metro Rapid on the Wilshire corridor.

- Some **technologies** can easily be added as additional budget becomes available while the system is already in operation, such as in Boston, MA or as it would be advisable in Sao Paulo, Brazil.

In fact, it is BRT's flexibility that overcomes obstacles and allows transit agencies to deliver high quality transit service despite such difficulties as tight budgets, narrow right-of-way, inter-jurisdictional disagreements, and others.

Based on this review, it is not certain whether generally representative deployment phases can be defined. It is more likely that as a transit agency proceeds with planning it needs to have a thorough understanding of BRT system components so that it can take maximum advantage of BRT's flexibility in case opportunities present themselves.

All transit agencies have experience in deploying bus routes. BRT takes bus system planning further. Planners can be bolder and explore more innovative choices. Almost all major city transit agencies have experience with light rail planning and operation. BRT gives the option of putting a "light-rail-like" system where a real light rail system would not work. Transit agencies need to know about the possibilities offered by the variety of BRT elements, the possible choices within each element, what the requirements are for each component, and how they depend on each other and affect each other.

2.6 Development of a Framework for Determining Optimal Deployment Phases

Bus Rapid Transit systems combine the flexibility of buses with the higher performance characteristics of fixed guideway (rail) operations. Unlike rail systems, however, because buses are self-guided and can operate over any right of way with sufficient width, BRT systems need not achieve a certain stage of development before operations can begin. BRT can be considered to be "treatment" of a traditional bus corridor, with any number of a wide variety of "elements" including: infrastructure and rights of way enhancements, segregation of parts or all of the rights of way, new vehicle types, automated vehicle guidance systems, improved stops and shelters, enhanced traveler information on-board and at transit stops, and new product identification and marketing approaches. Many practitioners would agree, however, that BRT must include a minimum level of improvements to legitimately be named as such, including a significant decrease in travel times in the corridor, and significant new branding and marketing for the route.

Many BRT corridors are typically deployed beginning with an "enhanced" treatment of urban buses operating in mixed traffic, and proceeding to a more complete approach with some segregation, signal priority and other ITS and traveler information applications. This project seeks to assist the transit community with tools to understand and optimize this deployment process of the BRT elements over time. In developing the deployment strategy for a BRT corridor, transit agencies must answer:

1. Into how many phases should the deployment process be divided?
2. When should these deployment phases occur?
3. Which elements should be deployed at which phase?

Under the following constraints:

1. Projected budgets at each phase
2. Elements that are pre-determined by the agency (or other stakeholders) to occur in each phase.

Within these constraints there is considerable room for improving the deployment process and the benefits derived from the project over its service life. Savings may be made by coordinating parts of the deployment, and likewise, greater benefits can be made by the synergy between certain groups of elements.

Why doesn't current practice in implementation and deployment of urban rail systems, developed over the past 15 years of experience with last generation light rail systems, apply to BRT systems. BRT has the advantage of being more flexibly implemented, and therefore can be implemented over phases, unlike rail.

Operationally, BRT systems running in segregated rights of way differ very little from traditional at-grade rail (light rail) systems. The approach of using level and multiple-door boarding, improved rider information concerning vehicle arrival times, longer stop spacing than local bus service, and precision docking and guided lane assist, seeks to emulate the more dependable and generally faster rail services. Differences remain however between ride quality, local emissions, vibration and noise, and some operational aspects like minimum headway, maximum speeds and acceleration rates, etc. Some of these are insignificant, while some are shown to have real influence on the attractiveness and the levels of performance of the systems – sometimes in favor of BRT, and sometimes in favor of light rail.

In general, little difference can be shown to exist between the peak carrying capacities (pass/hour/direction) of BRT and light rail systems. Some difference has been cited in the literature between the attractiveness of the systems, in favor of light rail, but this is still questionable. The permanence of tracks, the "romance" of urban rail, memories of turn of the century streetcars and the poor reputation of local bus service all contribute to this bias. Questions remain about this comparison, however, because few if any of the urban bus and BRT systems have been treated with the same level of urban design and landscaping of the recent light rail examples. For good sources on these comparisons, see References (3), (6), (7) and (8).

The deployments of the two systems however, are extremely different. Rail systems must be deployed in one single phase (though they can be phased by line or segment of a line), meaning all of the ancillary power systems, tracks, stations and platforms, signaling and switches, as well as the extensive parts of the system which bring cars into and out of storage and maintenance yards, must all be functional before the first day of operation. Bus Rapid Transit systems can begin operation as soon as new operational and marketing plans are developed. That is, as a first step, existing buses and stops can be used in conjunction with a new regime of service, which will approximate the future BRT system. From there, elements can be added: new shelters, new buses, new traveler information systems, and new segregated rights of way. And this can happen over any number of phases. In fact, a "final" long-term phase for BRT implementation is often implied to be conversion to light rail, demand warranting.

Not well covered in the literature, is the issue of system deployment. There is some material, but it is normally confined to specific issues with certain BRT elements or combinations of specific element, or more general guidelines (9) and (10). In Reference (10), the authors present two deployment strategies for a low and high demand scenario, and they do discuss some guidelines for decision making for deployment decisions. This project will expand on that work by treating this deployment decision through a more holistic discussion of combinations of BRT elements. The decision making processes for each agency, including funding possibilities and stakeholder desires, are so varied, that in this work, we hope to address deployment in a more flexible and interactive way.

This chapter begins with background about the general deployment problem and the theory behind the optimization of the deployment process. A simplification of the problem is presented, followed by a discussion of some of the drawbacks of optimization. Next, a decision visualization tool formulated and presented. The overall framework for the decision tool is introduced, followed by more details about the individual decision threads, and the individual BRT elements.

2.6.1 The General Deployment Problem and Optimization of the Deployment Process

Bus rapid transit systems deployment means, in the most general specification of the problem, implementing a BRT element at some time until all elements are deployed. The decision to deploy element I at time step T will depend on the state of the system at time T (which depends on the elements already deployed previous to time T combined with other characteristics of the system such as ridership, etc) and the impact of the deployment of element I at time T (reward). This amounts to a standard Markov Decision Process (MDP), where each state is some combination of deployed elements, budget, and the system characteristics, while the actions to take are the decisions to deploy certain elements based on that state. For an initial state, there is an optimal set of decisions, which produces the maximum benefit over the life of the project. This set of decisions is the deployment process, specifying exactly when each element should be deployed.

This is very complex problem, as each state is a combination of the time period, and the elements thus deployed, resulting in thousands of states. Tools exist to solve such a large problem, but it is not an easy problem to set up. It could also be simplified by grouping certain elements together, and restricting the time periods during which elements can be deployed, discussed below.

To simplify the problem extensively, we can assume that budgets and time points for implementation are fixed. This leaves our attention for which elements to chose. For example, in Figure 3 below, two phases are available for deployment of BRT elements, each with budgets, and certain pre-chosen elements. These define the constraints of the problem. From there, the problem is stated at a "knapsack" problem. For each budget (deployment phase) there exists some combination of elements whose total costs meets the budget constraint, and creates greater benefits that all other combinations of elements. The "benefits" are seen to rise after each budget phase, and over time as ridership naturally grows. These candidate groupings of elements are called knapsacks (originally because it invoked the image of a mountain climber who wanted to maximize the utility of items which fit inside his or her knapsack). There are myriad candidate knapsacks, which fit inside each budget (imagine all of the possible combinations of 20 elements – there are millions), but only one, which creates the maximum benefit. Finding this optimum knapsack is a tractable problem and there are techniques for solving it.

Clarifying the time-dependent and ordering aspect of the problem is more difficult. This includes various rules involving the required or optimal order of deployment (for example: you need to implement vehicle location tracking before you have traveler information or signs announcing headways to the next vehicles). Many such relationships exist between different BRT elements, and these need to be clearly defined for the model to be able to follow these rules and find the optimum combinations. This problem is more tractable and more realistic than the full MDP optimization, but still, it faces some real challenges in becoming a tool agencies can realistically incorporate into their decision making process.

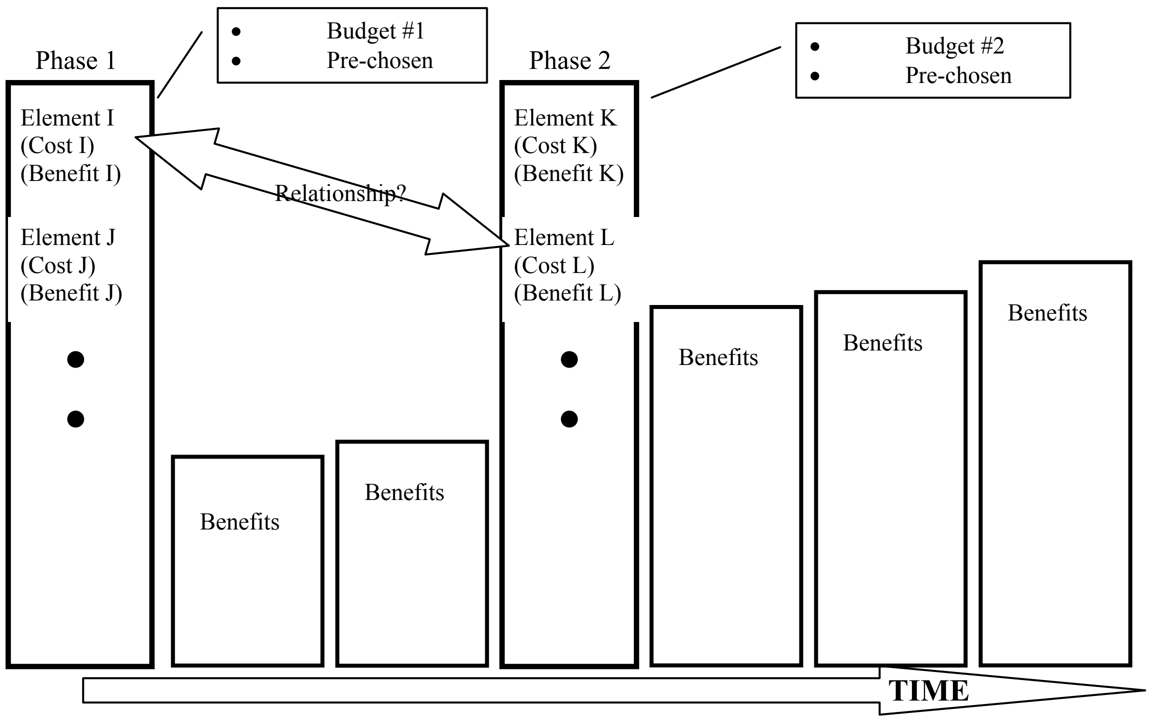


FIGURE 3 The Simplified Deployment Problem.

There are several problems with translating either the full MDP into a realistic depiction of an actual deployment process. The most important one is that there is no commonly agreed upon "benefit" (or objective function) which agencies attempt to maximize. Which of the following would an optimal deployment process maximize?

- Corridor ridership
- Number of new riders
- Number of choice riders
- Total time saved (With respect to what initial measure of travel time?)
- Some measure of consumer surplus
- Fare-box recovery rate

A second major problem is that the impacts of many BRT elements are unclear, and cannot be translated easily into an objective function (whatever that function may be). Assisted guidance systems can narrow the width of right of way, which can save capital expense, but its impacts on ridership are unknown. Traveler information can add convenience, but again, there are no impacts on transit performance or travel time, and so it's difficult to incorporate these improvements into a strict optimization model.

A third problem is that the model will be highly sensitive to approximations made about BRT service, impacts and other characteristics which vary heavily along the length of the corridor. Segregated right of way is an important element in BRT systems, yet few systems are entirely segregated. How does the 'degree' of segregation translate into a state in the MDP? Similarly, how does "signal priority" translate, when few intersections along the length of a BRT corridor may be given signal priority?

A fourth problem involves the definition of the phase – when should capital expenditures be used for implementation of BRT elements? For many agencies, this timing is not a choice, but is determined by the budget possibilities of the agency, of the timing of federal and state grants, and ultimately by the "political" window of opportunity.

Simplifying a deployment optimization model which can be run, and which reflects the objectives of the agency is possible, yet is it desirable? Agency staff is under political pressure from their boards, the communities, consultants and other local stakeholders. Funding sources are often not defined, and many times pieces of a BRT deployment are placed into project queues, which wait for available funding as it becomes available. For example, the following language from AC Transit's Major Investment Study for BRT in the San Leandro to Berkeley corridor illustrates this dynamic process:

> "Most major transit projects have a complex funding package that includes a mix of federal, state and local funding sources. The mix of funding sources can fluctuate as the project's design and engineering details develop, and typically only reaches a final and set package when the project nears construction." (11)
>
> "Aggressive phasing, staging and leveraging will be needed to complete Phase II construction within the next five to ten years. Toward this end, it is suggested that the project be developed in a compartmentalized fashion, with discrete stand-alone elements that build toward completion of the ultimate project. The goal should be to have a backlog of projects, at a variety of cost levels, that are ready for immediate implementation if other programmed projects are delayed or if unanticipated revenue is discovered." (11)

Giving the agency a single deployment program from a complex optimization tool, a virtual "black box," when they are negotiating a highly dynamic process with funders and various stakeholders might not be what an agency needs to optimize it's deployment process. It might need to revisit and revamp the deployment program at various times.

In order to address some of these problems with optimization, we propose to develop a tool which can be combined with information about costs and benefits to reveal an optimal deployment process, but which presents decision makers with new and more insightful questions, rather than answers. It allows decision makers to understand tradeoffs involved in the deployment, where synergies might exist and where unnecessary or potential wasteful decisions might be avoided. It is a tool that will allow the user to explore the deployment process along different "threads" of the decision. By looking at the same deployment from different lenses or "threads," one can see, in new and revealing ways, how decisions made in one area relate to those made in another area.

At this stage in this work, we are not attempting to operationalize a tool to give a single solution to this optimization problem. We hope to explore, instead, what are the important tradeoffs involved in the decision, how agencies would most commonly approach such a problem, and how such a decision tool might be structured. A prototype visual tool is developed, showing the relationships between twenty common BRT elements and seven major decision "threads." Depending on the outcome of this research, we can make recommendations towards the development of a more operational decision tool. The decision tool resulting from this work will be qualitative - attempting to guide the decision maker through the extensive relationships between BRT elements. The following section describes the decision tool: the decision threads into which it is divided followed by the building blocks of the decision – the "elements" of BRT.

2.6.2 The Bus Rapid Transit Deployment Decision Tool

Bus Rapid Transit refers to the application of treatments or "elements" to a bus route, which improves its performance, quality, and "recognition" over typical urban bus operations. Access and design, engineering, operations and policy changes all combine to create a transportation corridor – many times a combination of levels of services and routes into one package. Combined, these elements make up a system, though, like any complex system there are distinct sub-systems about which specific decisions are made in the deployment process. These subsystems overlap and affect each other through the elements they incorporate.

Herein, these subsystems are called decision "threads" which all relate to one major group of decisions. The "vehicle" thread, for example, includes those elements related to vehicle purchases, such as the vehicles themselves, optional automated guidance systems, and other equipment such as fare gates, interior signs, or automatic passenger counters, which might impact the interior layout or other specifications of the vehicle purchase. The decision threads include:

1. Operations
2. Security
3. Vehicles
4. Guideway Design
5. Vehicle Guidance
6. Stops
7. Information
8. Marketing
9. Maintenance

Countless applications could be considered to contribute to BRT system development, but for this exercise, we focus on those most commonly attributed to BRT developments, and those that are deployed, rather than just implemented. Some are planning level or service interventions which aren't necessarily "deployed," per se, such as limited stop operations, but which are just configurations of service. There are several dozen elements that form the typical "toolkit" of BRT applications in the U.S. All of these are central to the BRT system, but here, we focus on deployment of elements, which consume capital and operating budgets that are incremental to the BRT implementation. All routes need planning and service configuration. Likewise, we do not treat marketing and branding activities that are known to be central to the success of BRT systems, since these activities should happen irrespective of the particular capital elements deployed in the BRT systems.

Furthermore, each element can have many configurations, so here we merely represent it as a general type or category of feature, leaving the specific configuration of that decision for later and more detailed discussions. The suite of individual elements making up most BRT systems include:

1. **Signal Timing/Phasing** – A retiming of signals in the corridor to improve flow of relevant BRT transit vehicle.
2. **Signal Priority** – Granting signal priority to BRT vehicles
3. **Station and Lane Access Control** – the degree to which the right of way or areas around stops are segregated for BRT vehicle. This can range from simply striping off lanes and areas around stops, to curbing and introducing barriers to restrict entry to only BRT vehicles.
4. **Collision Avoidance** – an ITS application facilitating the detection of a potential collision and the automated response of the vehicle in taking corrective action.
5. **Collision Warning** – an ITS application facilitating the detection of possible collision and can take the form of forward, rear, and side hazard warnings to assist the driver in taking corrective action.
6. **Vehicle Guidance (Lane Assist)** – an ITS application which automatically steers the bus, guided by any of a variety of technologies
7. **Precision Docking** – similar to lane assist, this ITS application allows buses to approach and dock at bus stop in precise locations, allowing for very docking very close to bus stop.
8. **Off-Board (Stop-Based) Fare Payment** – various payment schemes can be used to facilitate fare payment off-board, and these impact the design of the bus stop.
9. **On-Board Fare Payment** – typical fare-payment equipment are used for on-board payment.
10. **Advanced Communication System –** the backbone of advanced data and voice communications between the vehicle, driver and dispatchers and other computers for data archiving.
11. **Automated Scheduling Dispatch System** – allows real-time information about vehicle position, passenger load, schedule adherence, etc to inform vehicle dispatching and scheduling.
12. **Vehicle Mechanical Monitoring** – systems, which can monitor certain mechanical systems, can help to manage maintenance and detect possible problems.
13. **Vehicle Location Tracking** – automatic detection of vehicle location can assist with scheduling adherence, and feed information for traveler information systems.
14. **Traveler Information - Stop –** displays schedule and wait time for next vehicle to arrive at stop.
15. **Traveler Information - Vehicle** – displays stop information inside the vehicle

16. **Traveler Information - Person** – gives schedule, wait time and vehicle location information on the web, PDA, or cell phone.
17. **Pre-Trip Itinerary Planning** – gives the ability to plan trips in advance using web-based schedule information
18. **Archived Data** – stores data for planning and analysis purposes.
19. **Passenger Counter** – data can be stored for analysis and used real time for adjusting dispatching and schedule adherence.
20. **Silent Alarms** – can be triggered by drivers to signal an emergency to persons outside vehicle or back to operations center
21. **Voice/Video Monitoring** – on-board surveillance by camera and microphone

2.6.2.1 Overall Decision Framework Representation

An effective decision process for BRT deployment must appreciate how decisions concerning one area of deployment affect the others. These relationships affect the compatibility of elements and the order in which they can be deployed if they are chosen for deployment. The framework must illuminate these relationships so that they can be appreciated during the decision making process. What is proposed here is a series of flow-charts which can guide the decision makers though these relationships. It will not give distinct answers to any questions, but can reveal important questions and problems planners must resolve in order to make an optimal decision. The flowchart will guide planners through the decision threads, and point out relationships among the threads. These relationships can be noted by planners and explored before proceeding towards a decision regarding the thread, or particular element. Many times, these relationships involve dependencies between threads, which can save or add costs later on depending upon action taken at an early stage. For example, making decisions regarding new bus purchases can impact the design and operation of bus stops and making these purchases while considering these relationships could save money on stop design and other requirements of vehicle in lieu of those bus stop operational plans. Ignoring some of these relationships can lead to higher costs or potentially wasteful decisions in the long run.

To begin to explore how such a framework tool might work, a prototype tool was developed in *Microsoft Visio*[1] (12). The tool can be accessed on-line at:

http://path.berkeley.edu/BRT_Decision_Support_Tool. The following sections discuss the charts contained in the tool, beginning at the higher levels with the "Thread" table and the Venn Diagram, and proceeding through each element individually.

2.6.2.2 Thread Table

The decision framework begins with how each of the BRT elements can have impacts on any number of the decision threads listed above. Figure 4 shows how threads directly relate to elements. Threads are listed across the top, while elements are listed along the left side, creating

[1] Microsoft Visio is a drawing and diagramming tool that can assist the developer communicate ideas and concepts by means of visual diagrams. See http://msdn.microsoft.com/office/understanding/visio/ for more information.

a grid. Where elements are thought to have a major impact on decision-making threads, a black box appears. Looking across the threads, one can see how the different threads are linked via the elements they hold in common. Some elements affect numerous threads, and therefore making decisions about these threads will all be impacted by decisions regarding these particular elements and vice-versa.

	Operations	Vehicle Guidance	Guideway Design	Vehicle	Security	Traveler Information	Stops
Signal Priority	■						
Signal Timing/Phasing	■						
Archived Data	■						
On-Board Fare Payment	■			■			
Station-Based Fare Payment	■						■
Automated Scheduling Dispatch System	■						
Silent Alarm				■	■		
Voice and Video Monitoring				■	■		
Station and Lane Access Control	■	■	■				
Precision Docking	■	■	■	■			■
Vehicle Guidance (Lane Assist)	■	■	■	■			
Collision Avoidance		■		■			
Collision Warning		■		■			
Passenger Counting	■			■			
Vehicle Tracking	■			■		■	
Traveler Information – Vehicles				■		■	
Pre-Trip Itinerary Planning						■	
Traveler Information – Person						■	
Traveler Information – Stops						■	■
Vehicle Mechanical Monitoring				■			

FIGURE 4 Relationships Between Threads and Elements

2.6.2.3 Venn Diagram

In order to better appreciate the relationships between the threads, the table is translated into a Venn diagram, shown in Figure 5. Here, elements are laid out over the page and boxed by the Threads they affect. Many of the thread boxes overlap. Decision threads are the boxes with relevant elements listed inside them. This diagram better shows how decisions made concerning elements can affect various threads, and how those threads therefore overlap and are inter-related. One can see that, for example, decisions made about automated vehicle guidance systems will impact operations, guideway design options, as well as vehicles. Closing in on the individual pieces of the deployment decision, the next section discusses the individual decision threads.

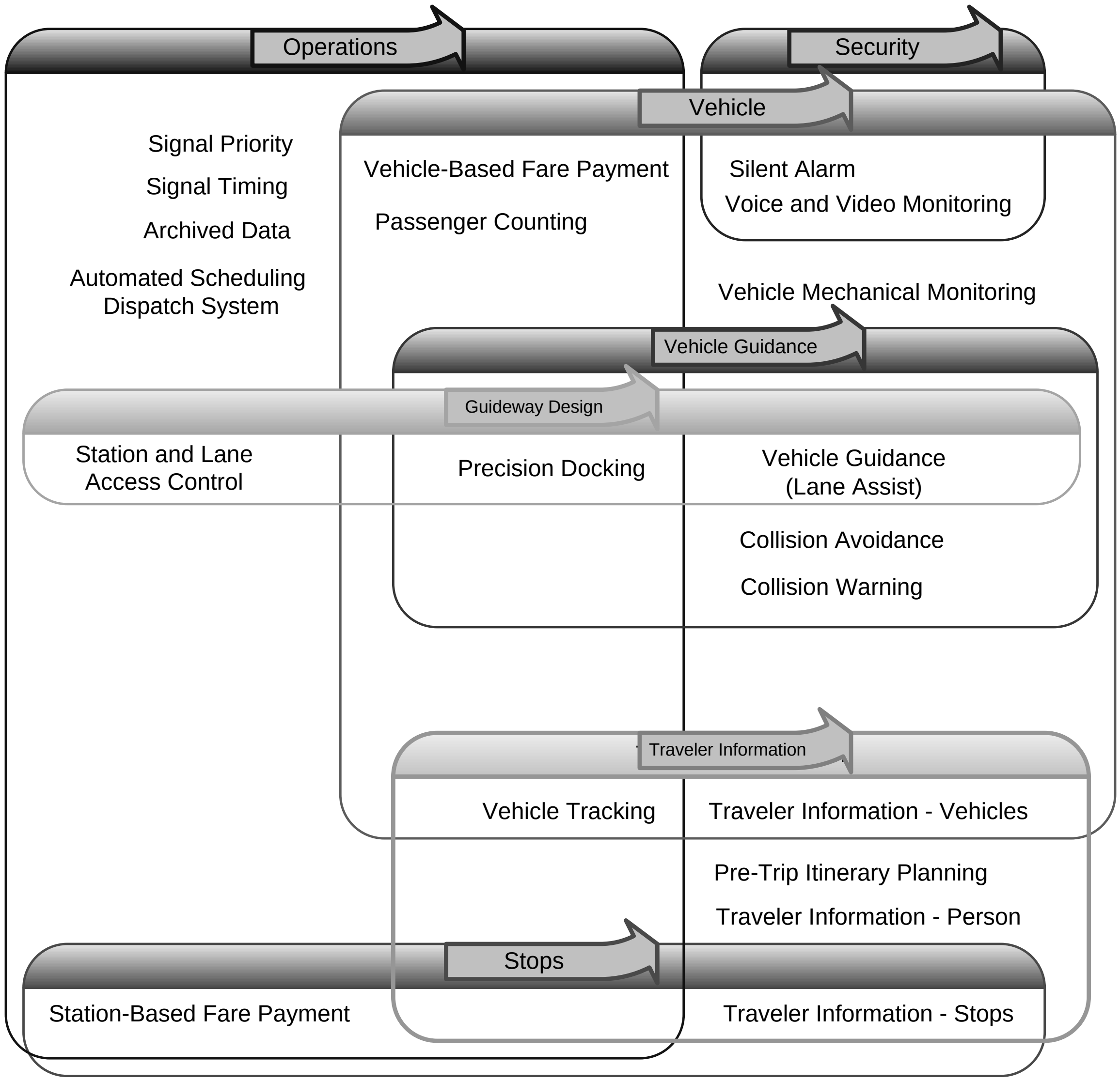


FIGURE 5 Venn Diagram for Overlapping Decision Threads and Corresponding Elements

2.6.2.4 Decision Threads

Stops

Stop placement is impacted by the type of express service planned for the BRT route, which is mostly a function of the demand and level of service offered by the service. Spacing is in effect a tradeoff between user access costs (of walking, etc) and costs to the agency and riders already onboard (in terms of delays from stopping). Longer spacing increases access costs but decreases delay costs. For high-ridership systems, such as most BRT routes, spacing should be longer to account for the higher value of time of the loaded bus, except where loading/unloading is particularly intense, such as in near job centers or dense residential areas. The design of the stop is impacted mostly by the type of fare payment system used, and whether it includes a "paid area" with stop based fare payment. Decisions made regarding precision docking might have some impact on stop design, because ramps deployed from platforms to make a level boarding to bus doors may or may not be necessary. Traveler information in the stops will demand space for signs and maps and appropriate power and communications.

Marketing

Marketing is a set of elements in and of itself, bearing no dependency on any of the other threads. Marketing, however, is seen by many practitioners, especially in Latin America, as extremely important to the success of the BRT lines. A strong marketing plan creating a clear brand identity for the lines should be part of the first phase of BRT implementation in order to capitalize on the new operational improvements and reach out to current non-users. Marketing is not included in the decision flowcharts because it is seen as essential, and in many respects, separate from the operational deployment of BRT elements. It must happen regardless of the particular technical aspects of the deployment.

Traveler Information

The type of traveler information available (at stops, on-person, and on-vehicle) will be dependent on the fitting of vehicles with vehicle locator devices in the operations decision thread. On-board traveler information will depend on having buses fitted with the proper sign systems for this type of information. Likewise, stops fitted for real-time information need to have the space, power and communications systems allocated for those systems. Traveler information on-person and pre-trip itinerary planning can be implemented independently of other decisions made in other threads.

Security

Improving monitoring for security purposes involves fitting buses with those cameras and microphone systems and advanced communication systems (ACS). Only the decision to implement ACS overlaps with other decision threads, and it is most likely that ACS will need to be in place before advanced security measures can be deployed. Vehicle fit with cameras and sensors and silent warning devices need to have the appropriate signs, spaces and power and communications for those systems.

Vehicle

The decision about vehicles for the BRT lines begins with whether to maintain a separate and non-interchangeable fleet only for BRT use. This would involve specifying a bus to match bus stop and other configurations of the service, right-of-way dimensions and projected peak demand. Other threads, such as automatic guidance systems can impact the vehicle decision greatly. Operations, especially scheduling for the BRT route will mainly impact the vehicle size needed to handle the peak link loads during service, and perhaps the interior layout.

Guideway Design

The level of segregation of the guideways, and how vehicle steering might be automated will impact the design and width of the guideways. Lane assist and precision docking can potentially reduce by around one foot, the width of the necessary right of way. Decisions need to be made about the deployment of these technologies, and in turn about the vehicles used, in order to proceed with guideway planning and design.

Vehicle Guidance
Highly interrelated to guideways and vehicle decision threads, automated vehicle guidance systems need to be resolved before guideway design and vehicle purchases can be made. Decisions made regarding precision docking might have some impact on stop design, as ramps deployed from platforms to make a level boarding to bus doors may or may not be necessary.

Operations
Decisions regarding operations will be an iterative process with nearly all of the other threads. As the different performance capabilities become resolved in the other decision threads, different operations plans can be finalized, and vice-verse: different operations approaches will demand different capabilities from the other threads of BRT deployment. The most interrelated are the issues of guidance and guideway control and segregation, signal priority, all of which impact strongly the travel times and variation in travel times, and fare payment type which impacts how/where users enter the bus and dwell time issues.

2.6.2.5 Elements

The deployment of each element is subject to a particular set of decisions, both technical and political. In this section each element is discussed, with some description of the element, along with particular issues concerning its deployment and its relationship to the deployment of other elements and threads.

Signal Timing / Phasing
Decision Threads: Operations

Description
Signal timing and phasing is a "passive" approach to reducing signal delay for BRT vehicles in a travel corridor. Signals along the corridor are retimed to better correspond to the travel speeds of transit vehicles. Because BRT corridors can often cross city and county boundaries, signal timing requires communications between multiple transit and traffic agencies to improve coordination.

Deployment Issues
Signal timing and phasing impacts Operations because it reduces signal delay and allows for faster and more predictable travel times. This impacts all aspects of service planning, scheduling, and fleet size and numbers of runs required to cover the route. Figure 4 shows the basic decision flowchart for the Signal Timing/Phasing BRT element.

Transit Signal Priority
Decision Threads: Operations

Description
Transit Signal Priority (TSP) is an "active" approach to reducing signal delay for BRT vehicles in a travel corridor. Traffic signal controllers at signalized intersections along the corridor are equipped to identify qualifying vehicles in order to grant signal priority (early green, extended green, skipped phase, etc). Vehicles can be given priority based on schedule adherence, passenger loading, time of day or time elapsed since last priority request, etc. Because BRT corridors can often cross city and county boundaries, TSP requires communications between multiple transit and traffic agencies to improve coordination. See References (2), (9), (10), and Section 3.3.4 of this report.

Deployment Issues
TSP impacts Operations because it reduces signal delay and allows for faster and more predictable travel times. This will impact all aspects of service planning, scheduling, timing transfers, fleet size and numbers of runs required to cover the route. Figure 6 shows the basic decision flowchart for the Signal Timing/Phasing BRT element. The decision to deploy TSP or new Signal Phasing will depend on the relative impacts on total intersection person-delay for each intersection considered, available time within the signal cycle, and the receptiveness to the idea of the public, operators and traffic management agencies, and local political actors.

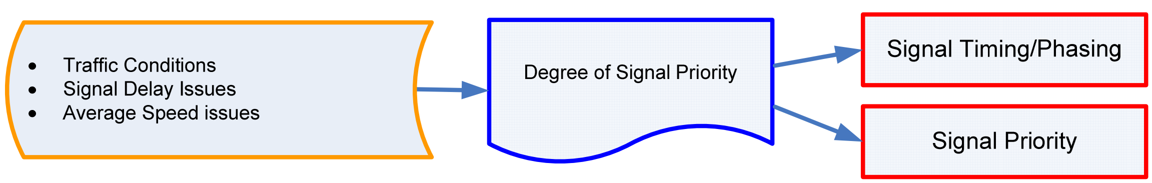


FIGURE 6 Decision Flowchart for Transit Signal Priority and Signal Timing/Phasing

Station and Lane Access Control
Decision Threads: Operations, Vehicle Guidance, Guideway Design

Description
The most successful BRT systems worldwide use some degree of guideway segregation to reduce congestion delay. Many applications of BRT in the United States will also incorporate segregated guideway sections into their systems. Station and Lane Access Control includes not only to the presence of guideway segregation, but also the technology of controlling access to the segregated sections of guideway. In many, but not all, areas it may be deemed necessary to physically control the access to the segregated sections. This control is based on identifying qualifying vehicles (transit vehicles, emergency vehicles, police vehicles or other) in order to trigger the opening of a physical gate or lowering barriers, etc. See References (2), (9), (10), and Section 3.3.4 of this report.

Deployment Issues

Figure 7 shows the basic decision flowchart for the Station and Lane Access Control BRT element. Within the decision making thread of Guideway Design, the degree of segregation is a central question, as segregation dictates many aspects of stop design and layout, intersection treatments, traffic engineering, as well as needed automated guidance systems. It also impacts operations because it reduces congestion delay and allows for more predictable travels times, which impacts all aspects of service planning, scheduling, timed transfers and fleet size and numbers of runs required to cover the route. Station and Lane Access Control also affects Vehicle Guidance because certain configurations of segregated guideways can be used with assisted guidance systems (Lane Assist) and guideway width and design are impacted by these guidance systems. With Lane Assist, vehicles track straighter and a narrower right of way is needed, saving valuable road space.

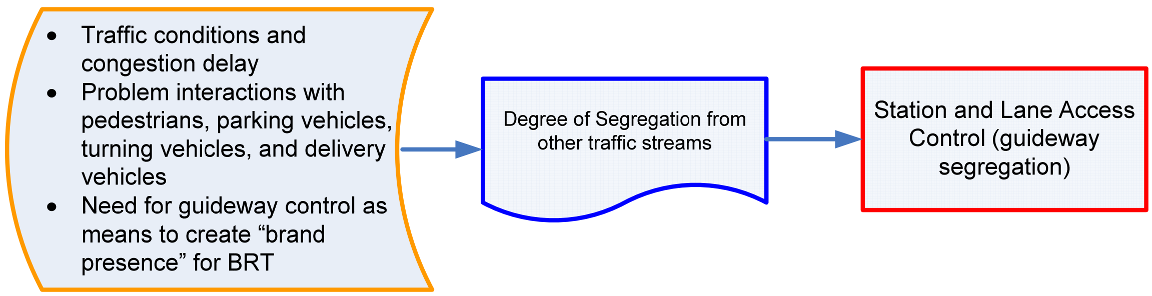


FIGURE 7 Decision Flowchart for Station and Lane Access Control

Collision Warning
Decision Threads: Vehicle Guidance, Vehicle

Description

Paraphrasing from Section 3.3.5 of this report, Collision Warning…

> …can warn drivers in the case of an impending accident, or help to make drivers aware of intersections or conditions with a high probability of accidents. These capabilities require 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 using on-board sensors to monitor the areas to the sides of the vehicle and present warnings to the driver about potential hazards. This feature will determine the probability of a collision in a (pre-equipped) intersection and provide timely warnings to drivers in the presence of 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 driver of the approaching transit vehicle using a short-range communications system (2).

Deployment Issues
Figure 8 shows the basic decision flowchart for the Collision Avoidance and Collision Awareness elements. The compatibility and installation of the equipment to enable these features must also play into the decision regarding purchasing or allocating vehicles for use in the BRT system. New vehicles should be appropriate for use with this feature and existing vehicles used should also be ready for being fit with the equipment.

Collision Avoidance
Decision Threads: Vehicle Guidance, Vehicle

Description
Paraphrasing from Section 3.3.5 of this report, Collision Avoidance…

> …can steer, slow or stop the vehicle the case of an impending accident. These capabilities require on-board sensors to monitor the areas in front of and behind the vehicle. In the case that other vehicles' trajectories or other impediments, pedestrians, etc pose a potential thread of an accident, this feature calculates the needed evasive action to be taken by the vehicle to avoid or reduce the impact. Monitors in the roadway infrastructure assess vehicles' locations and speeds near an intersection (9) and (10).

Deployment Issues
Figure 8 shows the basic decision flowchart for the Collision Avoidance and Collision Awareness elements. As collision avoidance interacts with the guidance of the vehicle, this makes up an important part of the consideration of different Vehicle Guidance approaches. There might be synergies between the steering and braking control systems used for other aspects of guidance deployed, and the collision avoidance system. The compatibility and installation of the equipment to enable these features must also play into the decision regarding purchasing or allocating vehicles for use in the BRT system. New vehicles should be appropriate for use with these features and existing vehicles used should also be ready for being fit with the equipment.

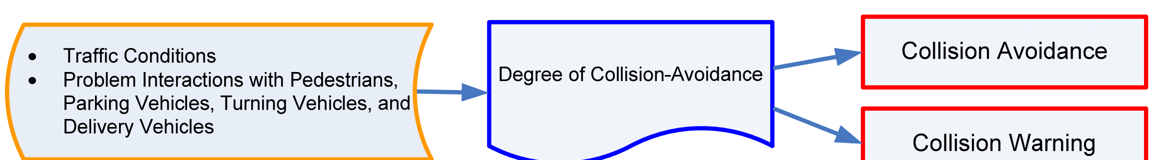


FIGURE 8 Decision Flowchart for Collision Avoidance and Collision Warning Elements

Precision Docking
Decision Threads: Operations, Vehicle Guidance, Vehicle, Guideway Design, Stops

Description
This feature automates the docking of the BRT vehicle at the loading area to within very precise tolerances, enabling the positioning of the vehicle extremely close to the curb. This allows a precise and level vehicle docking, quickly and without the need for deployment of a flip-out or protruding ramp. The bus is maneuvered into the loading area and then the mechanisms

automatically dock the vehicle into the stop. Sensors continually determine the lateral distance to the curb, front, and rear, and the longitudinal distance to the end of the bus loading area in order to control movement See References (2), (9), (10), and Section 3.3.5 of this report.

Deployment Issues

Figure 9 shows the basic decision flowchart for the Precision Docking element. Precision docking impacts decisions made about operations, vehicle guidance, vehicles, guideway design and stop design. By speeding and making more precise the vehicle docking, this feature can reduce dwell times, allowing for faster and for more predictable travels times, which impacts all aspects of service planning, scheduling, timed transfers and fleet size and numbers of runs required to cover the route. It also precludes the need for deploying a swing-out ramp to facilitate true level boarding, which can impact decisions being made about vehicles and stop design. Since precision docking is a type of automated guidance, decisions about systems used for higher speed automated guidance (lane assist) and collision avoidance should be made in conjunction with decisions about precision docking. There will be synergies between the steering and braking control systems used for other aspects of automated guidance deployed and the precision docking system. (In fact, it may be using the same system, only with more densely spaced guidance markers near the stops.) Similar to earlier systems, the compatibility and installation of the equipment to enable these features must also play into the decision regarding purchasing or allocating vehicles for use in the BRT system. New vehicles should be appropriate for use with these features and existing vehicles used should also be ready for fitting with the equipment.

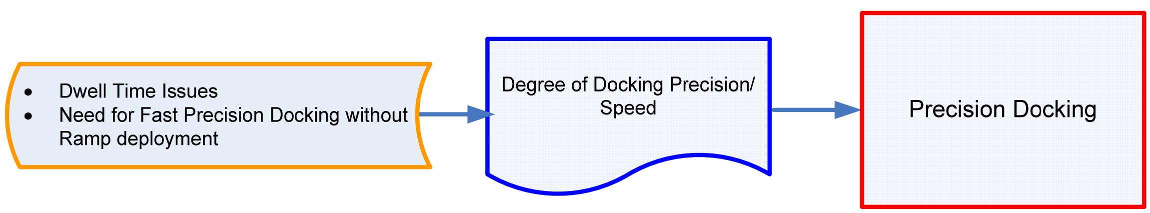


FIGURE 9 Decision Flowchart for Precision Docking

Vehicle Guidance (Lane Assist)
Decision Threads: Operations, Vehicle Guidance, Vehicle, Guideway Design

Description
This element enables fully automated "hands-off" operation of the BRT vehicle on the automated portion of the guideway. Implementation requires lateral lane holding, vehicle speed and steering control, and right of way check-in and check-out, using sensors on the roadway and the BRT vehicle. Vehicle Guidance (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. Straighter tracking allows the use of narrower rights of way See References (2), (9), (10), and Section 3.3.5 of this report.

Deployment Issues
Figure 10 shows the basic decision flowchart for the Vehicle Guidance (Lane Assist) element. Vehicle Guidance impacts decisions made about operations, vehicle guidance, vehicles, and guideway design. By speeding and making more precise the vehicle tracking, this feature can provide faster and more predictable free-flow (between stops) travels times, which impacts aspects of service planning, scheduling, timed transfers and fleet size and numbers of runs required to cover the route. Decisions about systems used for slower speed automated guidance (precision docking) and other high speed systems like collision avoidance should be made in conjunction with decisions about Vehicle Guidance, as there might be synergies between the steering and braking control systems used for these systems. Again, the compatibility and installation of the equipment to enable these features must also play into the decision regarding purchasing or allocating vehicles for use in the BRT system. New vehicles should be appropriate for use with these features and existing vehicles used should also be ready for fitting with the equipment.

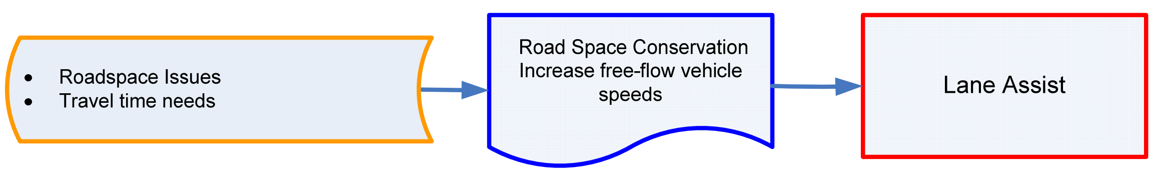


FIGURE 10 Decision Flowchart for Vehicle Guidance

Automated Scheduling Dispatch System
Decision Threads: Operations

Description
This feature utilizes real-time vehicle data (location, schedule adherence, passenger counters) to manage all BRT vehicles in the system and insure level of service meets pre-determined guidelines. For instance, if real-time passenger counters show a higher than normal loading, additional vehicles could be deployed into service to meet agency crowding guidelines. Likewise, if vehicles fall behind or become bunched, real-time location information can assist dispatchers with fixing the problems. This feature requires a communication system and real-time vehicle location and real-time passenger counter components. This feature performs vehicle

routing and scheduling, as well as automatic driver assignment and system monitoring. This service determines current schedule performance using AVL data and provides information displays at the central Transit Management center. A central dispatching unit responsible for processing the real-time data and making decisions about schedule and dispatch adjustments must be located in some central unit of the transit agency See References (2), (9), and Section 3.3.6 of this report.

Deployment Issues

Figure 11 shows the basic decision flowchart for the Automated Scheduling Dispatch System. This element impacts decisions concerning operations by controlling scheduling and deployment decisions which impacts aspects of service planning, scheduling, timed transfers and fleet size and numbers of runs required to cover the route. Real time schedule and dispatching adjustments, for example, might be impact the scheduling for the BRT routes, such as the location of time-points or minimum or maximum experienced headways.

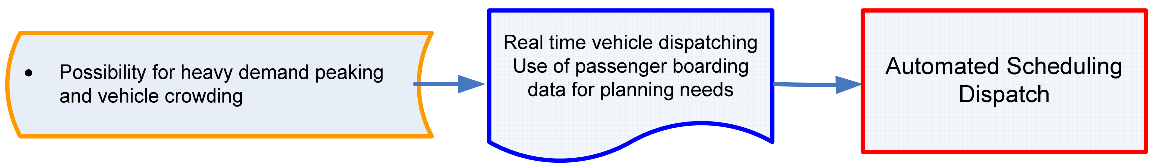


FIGURE 11 Decision Flowchart for Automated Scheduling Dispatch System

Vehicle Mechanical Monitoring
Decision Threads: Vehicle

Description

Paraphrasing from Section 3.3.6 of this report, Vehicle Mechanical Monitoring…

…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 center, hardware and software in the center processes this data and schedules preventative and corrective maintenance. These features must be compatible with vehicles purchased or allocated for its use in order to be available. A central unit responsible for processing the sensor data and making decisions about maintenance schedule and must be installed and located in the appropriate bus yards and garages. See References (2), (9), and (10).

Deployment Issues

Figure 12 shows the basic decision flowchart for the Vehicle Mechanical Monitoring system. The desire to deploy a mechanical monitoring system might impact decisions regarding vehicle purchases or allocation to BRT service, or the decision to implement such a monitoring system fleet-wide.

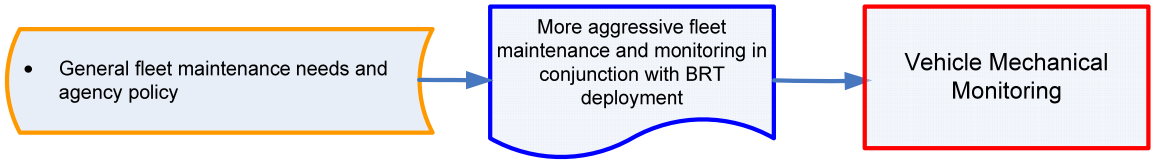


FIGURE 12 Decision Flowchart for Vehicle Mechanical Monitoring

Vehicle Location Tracking
Decision Threads: Operations, Vehicles, Traveler Information

Description
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 used with an Automated Scheduling Dispatch System to adjust service. 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. The Transit Management center processes this information, updates the transit schedule and makes real-time schedule information available to the passenger information 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 See References (2), (9), (10) and Section 3.3.6 of this report.

Deployment Issues
Figure 13 shows the basic decision flowchart for the Vehicle Location Tracking elements. The decision to deploy vehicle-tracking capabilities is important to the implementation of other BRT features including operations, vehicles, and traveler information. Real time monitoring of vehicle location is used for automated scheduling and dispatch systems, and can help adjust schedules, impacting approaches taken to operations, scheduling and other service planning. Depending on the type of signal priority system used, vehicle location may play a central part in providing data to the signal priority system, and the deployment of these two elements therefore must be made together. Likewise, some types of traveler information systems giving real-time vehicle arrival and location information must be deployed in conjunction with the vehicle location tracking capabilities.

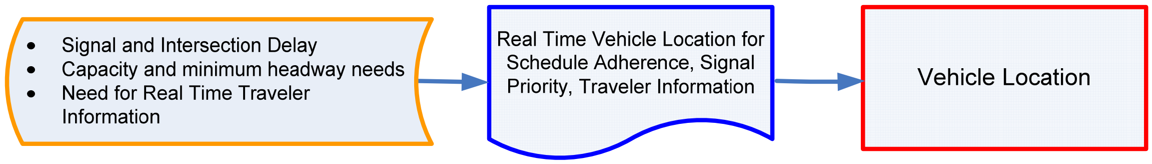


FIGURE 13 Decision Flowchart for Vehicle Location Tracking

Archived Data
Decision Threads: Operations

<u>Description</u>
This element creates an archive that houses data collected and owned by a single agency, district, private sector provider, research institution, or other organization. This archive includes data that is collected from vehicle sensors (passenger counters, vehicle maintenance systems, etc.) for future planning purposes or analysis. It provides for the basic data quality, privacy, and management common to all ITS archives and provides general query and report access to archive data users (2), (9), and Section 3.3.6 of this report.

<u>Deployment Issues</u>
Figure 14 shows the basic decision flowchart for the Collision Avoidance and Collision Awareness elements. To the degree that archived data is incorporated into the process of operations planning, archived data can have an important impact on operations.

FIGURE 14 Decision Flowchart for Archived Data

Passenger Counting
Decision Threads: Operations, Vehicles

<u>Description</u>
This element provides automatic counting of passengers as they enter and exit the BRT vehicle. Data can be used in real-time for vehicle operations, real-time scheduling 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 (2), (9), (10).

Deployment Issues

Figure 15 shows the basic decision flowchart for the Passenger Counting element. This element only affects decisions made about operations if a real-time automated scheduling and deployment system is deployed using passenger loadings as an input to decisions. Real time schedule and dispatching adjustments, in turn, might impact the schedule policy for the BRT routes, such as where time-points are placed, or minimum or maximum experienced headways.

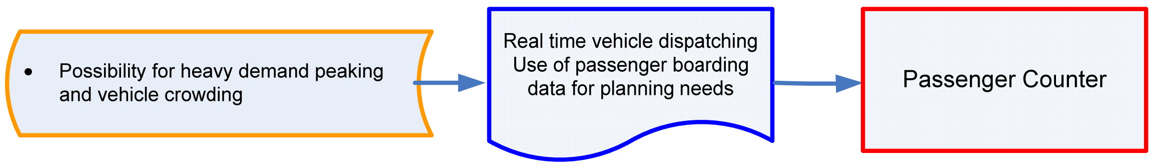


FIGURE 15 Decision Flowchart for Passenger Counting Element

Station-Based Fare Payment
Decision Threads: Operations, Stops

Description

The feature of having passengers pay fares to "board" a paid area in the bus stop before entering the bus is common in BRT systems in Latin America. This greatly decreases boarding time by eliminating interactions with the driver, enabling passengers to board and alight through multiple doors simultaneously. It is by far the fastest boarding scenario compared to any kind of on-board payment scenario, however fast. The same electronic fare card readers, ticket vending machines, etc, which are located on-board, can be located in the barriers to the stops' paid area. The same remote fare management systems can be employed to verify fare cards, count passengers and fares and allow two-way communication to the sites.

Deployment Issues

Figure 16 shows the basic decision flowchart for the Stop-based Fare Payment elements. There is no reason that stop-based fare payment can't be used in conjunction with on-board fare payment. Particularly impacted stops can be prepaid, allowing fast dwell times, while other "secondary" stops can use on-board payment methods (presumably by fast electronic means). The particular configuration of prepayment, proof of payment, etc is a detail best left to agency policy, though it will have some impact on the exact implementation of on-board versus stop-based fare payment. This implementation can have a large impact, however, on the dwell time, and therefore should be made carefully considering the tens of thousands of seconds per service-day which can be gained or lost, depending on the boarding process.

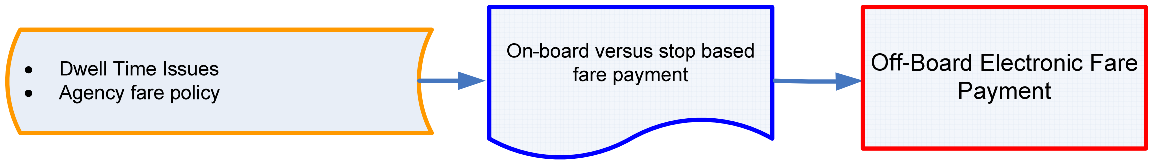


FIGURE 16 Decision Flowchart for Stop-Based Electronic Fare Payment Elements

On-Board Fare Payment
Decision Threads: Operations, Vehicles

Description
Here, passengers pay their fare or register their prepaid fare cards or electronic smart cards while entering the bus. Some configurations of On-Board Fare Payment can allow passengers to board through multiple doors simultaneously, but still cause some delay as some passengers fumble for their cards, the reader does not register immediately, passengers need to wait to pass by a reader, and some still pay cash with the driver. This element is really the status quo for most transit agencies as they move to electronic ticketing. Communications between the transit agency and the vehicle based fare readers can enable passenger counting and other data uploads (2).

Deployment Issues
Figure 17 shows the basic decision flowchart for the On-Board Fare Payment elements. On-board fare payment has some bearing on operations decisions given that its particular configuration will have some impacts on the dwell time, in turn on travel times, scheduling and fleet sizes and number of runs needed to cover routes. Choices of vehicle purchases or deployments to BRT service must be made in conjunction with the compatibility with the particular on-board payment equipment used.

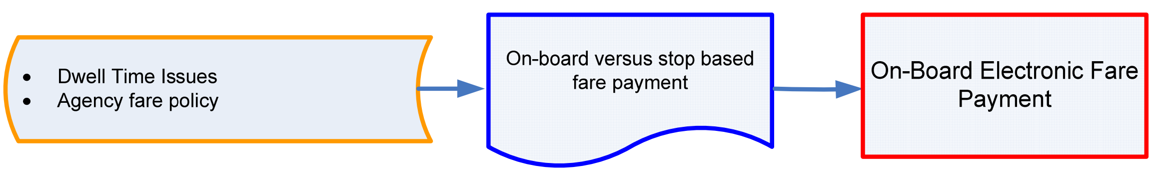


FIGURE 17 Decision Flowchart for On-Board Electronic Fare Payment Elements

Traveler Information - Stops
Decision Threads: Traveler Information, Stops

Description
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 and stops. This requires techniques to predict the vehicle arrival time and the ability to display this information at the station/stop (2), (9), and Section 3.3.8 of this report.

Deployment Issues

Figure 18 shows the basic decision flowchart for the Stop-based Traveler Information elements. Stops should be equipped with the proper communications and power needed to support planned and potentially planned Traveler Information systems. Also, needed data such as vehicle location must be deployed in conjunction with the traveler information systems.

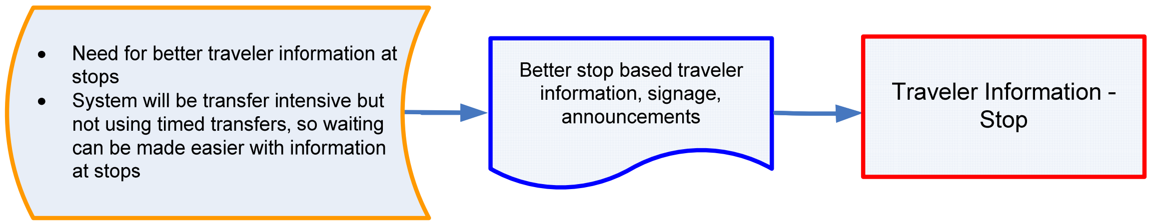


FIGURE 18 Decision Flowchart for Stop-Based Traveler Information - Stops Elements

Traveler Information – On-Board
Decision Threads: Traveler Information, Vehicles

Description

This element provides information about next stop, vehicle schedule, transfer or other bus information or delays within the system via dynamic message sign inside the vehicle. This requires real-time vehicle location data, techniques to predict the vehicle arrival time at the station/stop, receive data about other vehicles along the route and the ability to display the information to transit passengers riding inside the vehicle (2), (9), and Section 3.3.8 of this report.

Deployment Issues

Figure 19 shows the basic decision flowchart for the Vehicle-based Traveler Information elements. Vehicles must be equipped with the proper communications systems and signs, speakers, etc, needed to present the announcements and information. Also, needed data such as vehicle location must be deployed in conjunction with the traveler information systems.

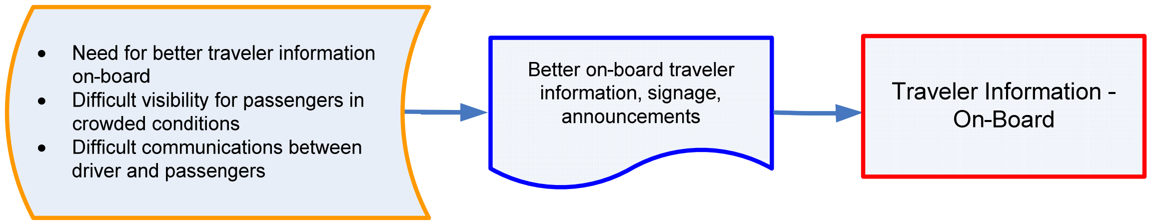


FIGURE 19 Decision Flowchart for Vehicle-Based Traveler Information

Traveler Information - Person
Decision Threads: Traveler Information

Description
The offering of on-person cell-phone and PDA information adds additional utility to the real-time vehicle location information displayed at stops, vehicles and on the internet. Combined with the other real-time information systems and pre-trip planning, this feature may allow for en-route trip planning and real-time updates. This element is more complex and costly that the other information systems (2), (9) and Section 3.3.8 of this report.

Deployment Issues
Figure 20 shows the basic decision flowchart for the On-Person Traveler Information elements. The deployment of portable traveler information capabilities should come in conjunction with the deployment of the other information capabilities and services and real-time vehicle location capabilities. In some cases, third party information providers which process the real time vehicle location and supply information to signs and announcements can also provide web and PDA based information.

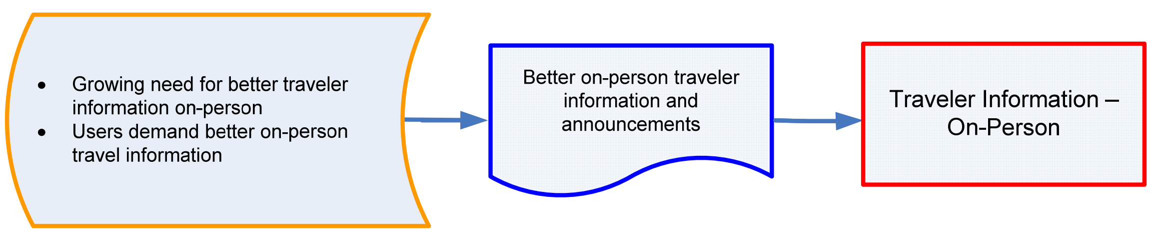


FIGURE 20 Decision Flowchart for On-Person Traveler Information Elements

Trip itinerary planning
Decision Threads: Traveler Information

Description
This elements provides a means for a traveler to request trip information via telephone or internet by specifying a trip origin and destination, arrival or departure time and date. It generates a trip itinerary, including a multimodal route and associated service information (e.g., parking information), based on traveler preferences and constraints. Routes and schedule information

may be based on static information or reflect real time network conditions, depending on the capabilities of the system (2), (9), and Section 3.3.8 of this report.

Deployment Issues

Figure 21 shows the basic decision flowchart for the Trip Itinerary Planning elements. The deployment of trip planning capabilities can come in conjunction with the deployment of the other information capabilities and services, but it is not necessary.

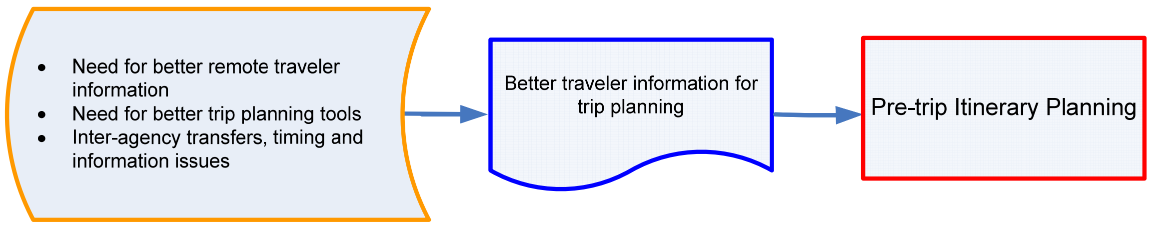


FIGURE 21 Decision Flowchart for Trip Itinerary Planning Elements

Silent alarms
Decision Threads: Security, Vehicles

Description

Silent Alarms are silent variable message displays and 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 and/or messages can be sent back to the operations centre to indicate an emergency problem. This element enables the user (driver or non-driver) to initiate a request for emergency assistance and enables the central transit management center 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. An Emergency Management center may be operated by the public sector or by a private sector service provider (2), (9), and Section 3.3.9 of this report.

Deployment Issues

Figure 22 shows the basic decision flowchart for the Collision Avoidance and Collision Awareness elements. The deployment of silent alarms must be joined by the formation of agency capacity to centrally monitor such alarms as well as the equipment and vehicles capable of using such systems and communications demands.

Voice and video monitoring
Decision Threads: Security, Vehicles

Description
On-board equipment is deployed to perform surveillance and sensor monitoring in order to warn of potentially hazardous situations or record situations for later use. The surveillance equipment includes video, audio systems and/or event recorder systems. The sensor equipment can include sensors (e.g., chemical agent, toxic industrial chemical, biological, explosives, and radiological sensors) and object detection sensors (e.g., metal detectors). The surveillance, sensor and any alarm information is transmitted to the transit operations and Emergency Management center (Section 3.3.9 of this report.)

Deployment Issues
Figure 22 shows the basic decision flowchart for the Voice and Video Monitoring and Silent Alarm elements. Like in the case of silent alarms, the deployment of monitoring systems must be joined by the formation of agency capacity to centrally monitor and record such data as well as the equipment and vehicles capable of using such systems and communications demands.

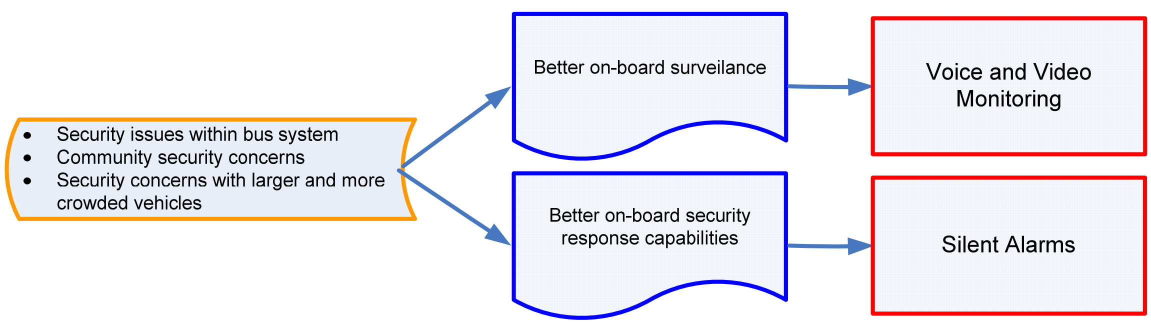


FIGURE 22 Decision Flowchart for Voice and Video Monitoring and Silent Alarm Capabilities

2.6.3 Case Study: AC Transit International Boulevard – Telegraph Avenue BRT

To understand how such a deployment decision tool might work for operators, the prototype tool is applied to a case BRT deployment proposal. Ideally, the proposed decision tool would accompany the planning and deployment process starting at its beginning. Since our group was not privy to such a process during the period this work was performed, we apply the tool to the already well-established case of AC Transit's International Boulevard – Telegraph Avenue BRT. The background information, demand analysis and projected service configuration contained in the Major Investment Study will be used as the source for this case study (11). We will go though each element decision as it is presented in the tool. We can then note the pattern of deployment decisions made, and any deployment problems, which might arise, based on the various interlocking decisions involved.

2.6.3.1 Background from Major Investment Study

The following summary paragraphs are condensed from the MIS documents (11).

The Berkeley/Oakland/San Leandro corridor stretches approximately 18 miles from downtown Berkeley at its northern end, through downtown Oakland to San Leandro at the southern end (see Figure 23). The service connects several times with BART and numerous cross-town routes and provides additional connections to the currently transit-poor areas of UC Berkeley south campus area, the Temescal neighborhood, the San Antonio neighborhood Buses in this corridor currently carry 40,000 riders a day. AC Transit and its partner cities of Berkeley, Oakland and San Leandro developed six transportation alternatives to carry forward for detailed evaluation. The stated service objectives were outlined in the MIS, and are as follows:

1. Improve access to major employment and educational centers and enhance connections to other AC Transit services, BART, ferry services and other transit providers;
2. Improve transit service reliability;
3. Provide frequent transit service;
4. Ensure security, cleanliness and comfort waiting for and riding on transit;
5. Support transit-oriented residential and commercial development;
6. Increase the percentage of trips made by transit, and reduce the percentage by automobile;
7. Identify a set of transit improvements that has a high probability of being funded;
8. Improve ease of entry and exit on vehicles for all transit riders, including persons with disabilities; and
9. Provide an environmentally friendly transit service that contributes to air quality improvement.

Based on the results of the detailed evaluation and extensive input from leaders of community-based organizations, the general public and elected officials, Bus Rapid Transit was recommended as the preferred vehicle and operations technology for the corridor. The BRT system is to be designed to maximize the ease of potentially upgrading to LRT in the future. The system is to include the following features:

1. Special transit lanes dedicated to BRT along most of the corridor;
2. Traffic signal priority and coordination throughout the corridor;
3. Frequent BRT service with a background local service (5 to 7.5 minutes between BRT buses);
4. Wider BRT station spacing than existing bus service (1/3 to 1/2 mile between BRT stations);
5. Well-developed BRT stations including shelters, boarding platforms, benches, security features, fare machines, real-time bus arrival information and other amenities;
6. Proof-of-payment ticket validation; and
7. Low-floor, multi-door, level-boarding, low-emission BRT buses.

Recognizing that implementing the full BRT program would take several years and several regional funding cycles to complete, the Policy Steering Committee recommended implementing selected elements of the Enhanced Bus alternative quickly. Features such as bus priority at traffic signals, bus stop improvements and redesigned bus routes would benefit corridor riders sooner while putting in place many of the elements needed in the eventual BRT system.

To provide fast, reliable BRT service, a special transit lane would be provided along most of the alignment. This includes the portions of the alignment on Shattuck Avenue; Telegraph Avenue; Broadway; International Boulevard; East 14th Street between the Oakland/San Leandro border and Davis Street; and East 14th Street between San Leandro Boulevard and Bay Fair Drive. To make this possible, the segment of Telegraph Avenue between Dwight Way and Bancroft Way near the University of California could be converted to a transit and pedestrian mall, permitting deliveries but with limited auto access.

Locally Preferred Alternative is proposed for deployment in the Berkeley/Oakland/San Leandro corridor. In Phase I, elements of the Enhanced Bus alternative would be implemented in the corridor along with selected parts of the BRT alternative. The full BRT system adopted would be completed in Phase II. Aggressive phasing, staging and leveraging will be needed to complete Phase II construction within the next five to ten years. Toward this end, it is suggested that the project be developed in a compartmentalized fashion, with discrete stand-alone elements that build toward completion of the ultimate project. The goal should be to have a backlog of projects, at a variety of cost levels that are ready for immediate implementation if other programmed projects are delayed or if unanticipated revenue is discovered.

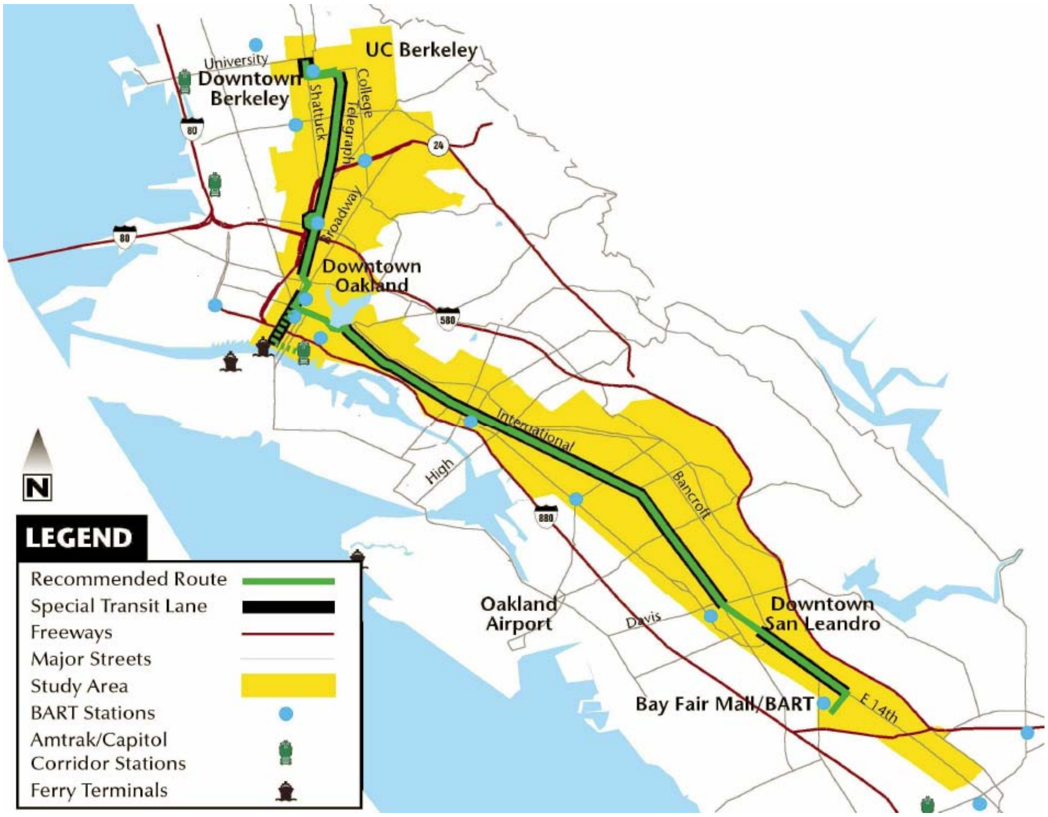


FIGURE 23 Study Area with Recommended Alignment for BRT System (Cambridge Systematics, et al., p. 134)

2.6.3.2 Analysis of Deployment via Decision Tool

The preceding section outlines how AC Transit envisions the main service objectives of the BRT corridor, along with some language about the deployment process. Two phases are proposed – one that adds some operational improvement to the status quo limited stop bus service, while the second adds additional capital improvements to bring the system up to BRT service. In the following section, each element decision will be looked at in light of more detailed language in the document for these two phases. From here, we can see which particular elements are planned for deployment according to the document, and then look at the overall deployment process and how it looks through the various decision threads. Each section below pertains to each element or groups of related element. For many elements, the particular approach was not clearly defined in the MIS, while for others, while approaches were not explicit, they could be inferred from language in the document and knowledge of the corridor and other AC Transit operations.

Signal Timing/Phasing and **Signal Priority** – Plans are, for both phases, to include signal priority at as many intersections as feasible and logical. Re-timing of the entire corridor is not mentioned explicitly, but some re-timing could occur as part of the traffic management system upgrades.

Station and Lane Access Control – Sections of segregation are part of phase 2, though the specific lengths, and methods for controlling entry and not detailed in the document. The method of segregation, whether it be striping, raised dividers (vehicles can pass over them, but only slowly) or curbing, is not defined.

Collision Avoidance and Collision Warning – No mention or plans are made in either phases for using automated guidance systems.

Vehicle Guidance (Lane Assist) – No mention or plans are made for deployment of this element in either phase.

Precision Docking – Mention is made that BRT systems could achieve close docking precision using automated features (p 64), but no plan is made about including such features in either phase 1 or 2. It will be assumed herein that plans are made for using precision docking at stops.

Off-Board (Stop-Based) Fare Payment – Phase 2 was to consider using proof of payment schemes where fare was paid off-board, in conjunction with smart cards and larger and more developed stop platforms.

On-Board Fare Payment – It is difficult to ascertain from the document whether all stations would be pre-paid in phase 2, or just a selection of stations. Phase 1 would continue with status quo on-board fare payment systems.

Automated Scheduling Dispatch System – No mention or plans are made for deployment of this element in either phase.

Vehicle Mechanical Monitoring – No mention or plans are made for deployment of this element in either phase.

Vehicle Location Tracking – Because real-time vehicle location information and signal priority is mentioned for phases 1and 2, the deployment of this element implied. It is assumed that this feature is deployed in phase 1.

Traveler Information - Stop – Real-time arrival information is mentioned as an important part of the stop upgrades for phase 2.

Traveler Information - Vehicle – No mention or plans are made for deployment of this element in either phase.

Traveler Information - Person – No mention or plans are made for deployment of this element in either phase.

Pre-Trip Itinerary Planning – No mention or plans are made for deployment of this element in either phase.

Archived Data – No mention or plans are made for deployment of this element in either phase.

Passenger Counter – No mention or plans are made for deployment of this element in either phase.

Silent Alarms – No mention or plans are made for deployment of this element in either phase.

Voice/Video Monitoring – These features are mentioned for application both on-board and in stations in Phase 2.

A next step is to view the deployment via the decision tool. To begin, the different elements' deployment by phases are tabulated in Table 13.

TABLE 13 Deployment of BRT Elements According to MIS

Element	Phase 1	Phase 2
Signal Timing/Phasing	**Maybe**	**Maybe**
Signal Priority	**Yes**	**Yes**
Station and Lane Access Control	No	**Yes**
Collision Avoidance and Collision Warning	No	No
Vehicle Guidance (Lane Assist)	No	No
Precision Docking	No	**Yes (?)**
Off-Board (Stop-Based) Fare Payment	No	**Yes**
On-Board Fare Payment	**Yes**	No
Automated Scheduling Dispatch System	No	No
Vehicle Mechanical Monitoring	No	No
Vehicle Location Tracking	**Implied**	**Implied**
Traveler Information - Stop	No	**Yes**
Traveler Information - Vehicle	No	No
Traveler Information - Person	No	No
Pre-Trip Itinerary Planning	No	No
Archived Data	No	No
Passenger Counter	No	No
Silent Alarms	No	No
Voice/Video Monitoring	No	**Yes**

By translating these deployment schedules into the main threads page in the deployment tool, we can see how the different threads are covered by the deployment plan. Figure 24 below shows, for each element, whether and in which phase, deployment is planned.

	Operations	Vehicle Guidance	Guideway Design	Vehicle	Security	Traveler Information	Stops
Signal Priority	1, 2						
Signal Timing/Phasing	?						
Archived Data	X						
On-Board Fare Payment	1			1			
Station-Based Fare Payment	2						2
Automated Scheduling Dispatch System	X						
Silent Alarm				X	X		
Voice and Video Monitoring				2	2		
Station and Lane Access Control	2	2	2				
Precision Docking	2	2	2	2			2
Vehicle Guidance (Lane Assist)	X	X	X	X			
Collision Avoidance		X		X			
Collision Warning		X		X			
Passenger Counting	X			X			
Vehicle Tracking	1, 2			1, 2		1, 2	
Traveler Information – Vehicles				X		X	
Pre-Trip Itinerary Planning						X	
Traveler Information – Person						X	
Traveler Information – Stops						2	2
Vehicle Mechanical Monitoring				X			

FIGURE 24 Translation of BRT Element Deployments into Deployment Tool Threads Page

Now, we can look through each decision thread separately. We can see that operations improvements are planned for both phases, with the tracking and signal priorities coming the first phase, followed by addressing dwell time and congestion delay issues in the second phase. Automated vehicle guidance systems don't become considered until the second phase, yet only the precision docking features are mentioned explicitly. Guideway Design improvements are left for the second phase. Vehicle changes are made in the first phase by implementing vehicle tracking, while on-board security improvements are made in the second phase. Traveler information elements are left mostly for the second phase, when they are implemented at stops, while the vehicle tracking capability is installed in the first phase. Stop improvements are left entirely for the second phase. Visualizing the elements this way can reveal patterns in the deployment process that can be improved or should be explored further. Some interesting points this reveals about the deployment process include:

- For operational improvements, it is interesting to note that phase 1 will attempt to address signal delay problems through transit signal priority, while leaving dwell time and congestion delay improvements for the second phase. This seems to make sense, depending on the relative significances of the delays, but also because improvements to the to the other systems which address dwell time (new stops) and congestion delay (guideway improvements) are left to the second phase. Thus, operational improvements on these fronts must wait for the second phase and these other improvements.

- Automated vehicle guidance systems are addressed in the second phase with precision docking. This feature could easily be extended to include collision avoidance and vehicle guidance systems, which could then impact safety, guideway design and lane width requirements. Since one guidance system approach (precision docking) is considered for deployment, the others should be considered as well, since it is possible to incorporate all of these designs using the same guidance system. Costs can also be saved in guideway development and higher speeds could be attained in operation, though decisions about guidance need to be finalized before design work begins on the guideway in order to take advantage of these synergies.
- Stop improvements seem to make the most sense in the second phase, as they will coincide with the construction of the guideway's segregated sections and improved intersections.
- Additional traveler information on-board could be made available, given that the real-time information is planned for station based announcements and the costs of vehicle location, central processing and distribution of the information are already being invested.

The tool seems to present a new way of looking at the issues of interdependency of BRT elements and can shed some light on the logic and progression of the deployment process. The two stage deployment process seems to work well here for AC, with a few important points for them to note as they proceed into the detailed engineering phase. Here, an established case was analyzed using the tool, though ideally, this visualization would take place during the initial planning of the phases. Questions remain, however, about the staging of this deployment. Phase 2 will presumably take place over a long period and involve many smaller "mini-phases" where certain parts of the project are deployed as funds become available. It is here where questions of the order of deployment of elements can be particularly important, and the decision tool might be useful. The tool reveals also that for elements such as vehicle guidance, it may make sense to deploy all of the features of automated guidance, rather than just one, in order to take advantage of some of the other performance impacts and cost saving potential of the other features.

2.7 Conclusions and Future Directions

A tool to assist in decision making was formulated and developed here to avoid problems associated with pure optimization. The deployment process is a highly dynamic process, involving various stakeholders, time-varying funding streams, which are not always predictable, and changing system characteristics and needs. It was thought that a tool could be developed to assist agency staff, consultants, community members and others involved in this highly complex process of deployment optimization. This tool could be used at any time during the decision making process, to update or check decisions or think about alternative approaches as conditions, funding or other variables change. A prototype of such a tool was developed, showing some promise as being an interesting and useful part of the decision making process.

Applying the tool for the AC Transit BRT corridor proved to be only of limited use, but it also reveals how improvements to the tool could make it much more powerful. At this stage, we can envision three ways the tool could be improved upon to assist transit agencies more effectively. Figure 26 shows a basic diagram for the three approaches.

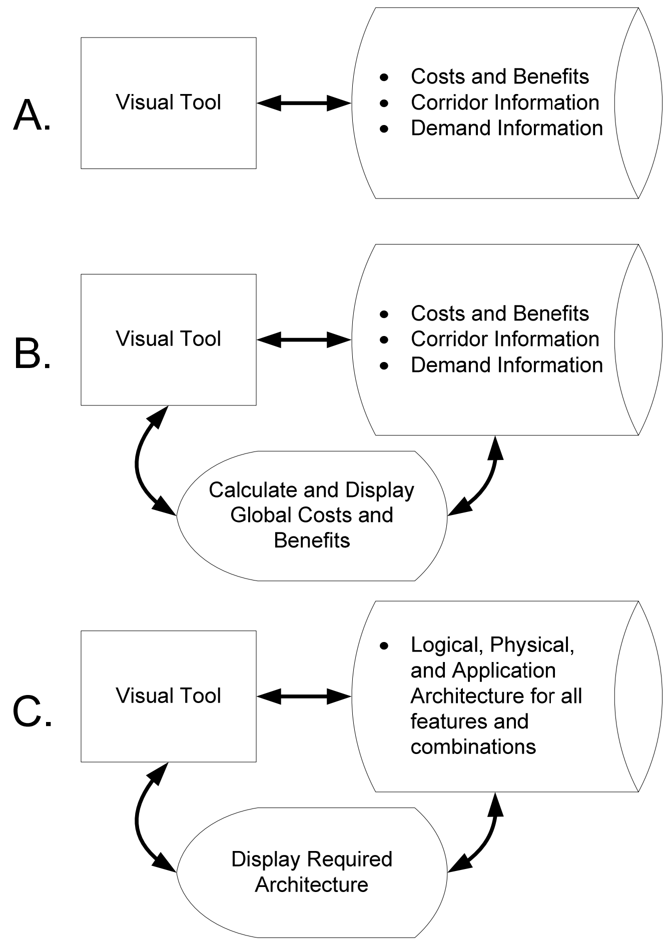


FIGURE 25 Three Approaches to Implementing Visual Tool with More Advanced Capabilities

The first and perhaps most advanced improvement (Improvement B in Figure 23) would use the visual tool as developed in the prototype as a user interface for a database of costs and benefits for the various elements, along with rules for costs and benefits of certain combinations of elements for the corridor in planning. The user would be able to modify the phasing of each element (or not include the element, of course) and be given global cost and benefit (however that may be represented) information for that particular combination of element deployment decisions. This would be the ultimate incarnation of the tool – allowing the user to see some global measure of costs and benefits as they modified the deployment decision. Unfortunately, it suffers from the same problems which plague optimization tools in general as discussed in the opening sections of this report.

A second and simpler approach (Improvement A in Figure 25) would be to use the current tool as a front end for such a database of costs and benefits, but not have it calculate any global costs and benefits. It would then merely serve as a front end for a simple database – allowing users, for example to click on items to reveal costs and these could be linked to characteristics of the corridor in planning. This is a simple task, and avoids the problems of translating different impacts into one global decision variable, such as cost, time, new riders, etc. It is also less useful, but it does add the useful feature of instant access to data and information as the user is going through the tool. In the prototype, the user is left with relationships only, but has no ideas about the magnitude of costs or benefits from the different element.

A third improvement approach (Improvement C in Figure 23) is to use the tool to assist in deployment organization after the deployment decisions have been made. The requisite BRT and information architecture needed for different arrangement of features is a complex problem involving hundreds of ITS and other data flow applications, physical features and architectures. By allowing the certain chosen element combinations to be input and translated via the tool into the corresponding architecture needs of the different features, the actual detailed engineering process for implementation of BRT elements could be assisted. This would in effect marry the extensive flowcharts for the various BRT and ITS applications developed in Hickman, et al., with the interface developed in this work.

Whether or not this tool is developed further, its development has allowed us to focus on a part of the BRT development problem, which is often overlooked. Understanding more fully the problem of deployment timing and synergies can undoubtedly lead to cost savings and an improvement in the effectiveness of projects. How this understanding can be incorporated and developed into typical deployment planning process is a difficult issue with numerous approaches.

3.0 DEVELOPMENT OF BUS RAPID TRANSIT ARCHITECTURE: A SYSTEM ENGINEERING APPROACH

3.1 Background Information

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 systems, 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.

ABRT 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 (2) and (9). 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 (2), (9), and (10).

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 (13), 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 (2) and (9). 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 3.4, 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.

3.2 Application Layer of Bus Rapid Transit Architecture: ITS Enhanced BRT Features

A schematic diagram of the National ITS architecture hierarchy ([4]) is shown in Figure 26. Motivated by this architecture, the conceptual framework of BRT architecture has a hierarchy of three layers: *logical, physical, application.*

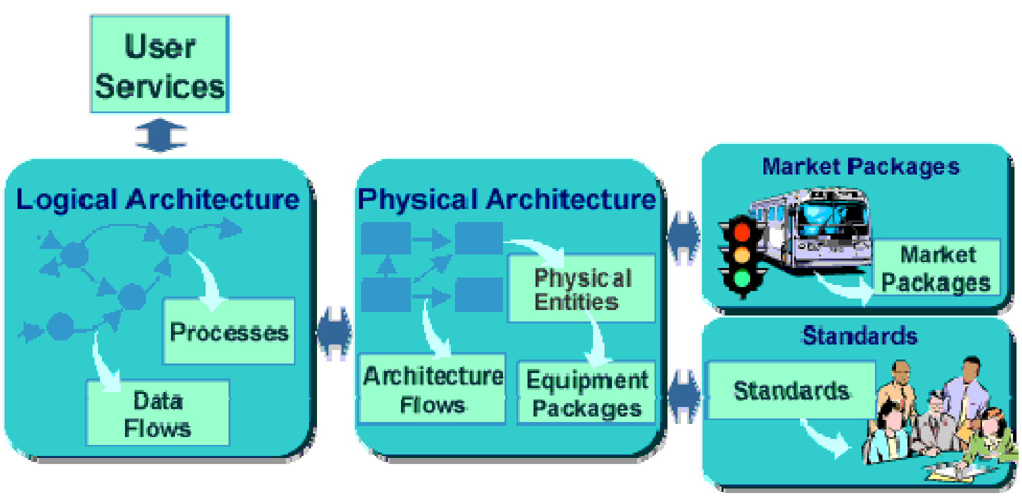


FIGURE 26 Hierarchical Structure of the National ITS Architecture

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 utilized 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 14. These features are taken from the "Characteristics of BRT Report" (2), the "ITS Enhanced BRT Report" (9), and the "TCRP-90 Report" (1) and (10). We have added fare collection, which is a separate area in (2), but left off "Advanced Communication Systems" as this is considered as a supporting technology, rather than a specific feature within BRT.

TABLE 14 ITS Enhanced BRT Features

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

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.

3.3 Representation of Bus Rapid Transit Features in the Physical Layer of the 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 (13). As described in previous work, e.g. (14), these concepts improve the presentation and analysis of the physical architecture, as it may be implemented locally or regionally.

3.3.1 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 (2), a report on "ITS enhanced BRT" prepared by the Mitretek Systems in 2003 (9), and the "TCRP-90 Report" by Levinson *et al.* published in 2003 (10). The first two reports (2) and (9) use a consistent representation of ITS features within Bus Rapid Transit; these we have labeled "BRT Features" and are listed in Table 14 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 (2), (9), and (10) 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.

3.3.2 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 (13). 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.

3.3.3 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 (13). 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 14.

3.3.4 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

<u>Description of feature</u>

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 ((2), p. 2-51) and ((9), p.15).

<u>Relation to National ITS market package(s)</u>: 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 ((2), p.2-51), ((9), 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 ((2), p. 2-52), ((9), p. 15), ((10), 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

3.3.5 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 utilizes 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 ((9), p.15), ((9), 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 utilizes 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 utilizes 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

Description of feature

This feature automates the speed and headway control functions on board the vehicle. It utilizes 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 utilizes 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 ((9) p.15), ((10), p. 7-16).

Relation to National ITS market package(s): 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 utilizes 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 utilizes 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 ((2) p. 3-5, p. 3-74), ((9), p. 16), ((10), 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 utilize 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 ((2), p. 2-54, p. 3-5), ((9), p.15), ((10), 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

3.3.6 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 utilize 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)

<u>Description of feature</u>

This feature utilizes 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 ((2), p.2-55), ((9), 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.

<u>Relation to National ITS market package(s)</u>: 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 ((2), p.2-55), ((9), p.17), ((10), 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 ((2), p.2-56), ((9), p.17), ((10), 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 ((2), p. 2-60), ((9), 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 ((2), p. 2-60), ((9), p.18), ((10), 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 “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”.

3.3.7 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

<u>Description of feature</u>

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 ((2), p. 2-39, 2-40), ((10), p.7-12).

<u>Relation to National ITS market package(s)</u>: 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 coordination	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 ((2), 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 coordination	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

3.3.8 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 ((2), p. 2-57), ((9), 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

Description of feature

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 ((2), p. 2-58), ((9), p. 18).

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.

Notes on architecture representation

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

<u>Architecture flows</u>

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

<u>Description of feature</u>

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 ((2), p. 2-58), ((9), 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 ((2), p. 2-58), ((9), 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	multimodal information

	Service Provider	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

3.3.9 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 ((2), p. 2-59), ((9), p. 18).

Relation to National ITS market package(s): 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.

Notes on architecture representation

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 ((2), p. 2-58), ((9), 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.

<u>Notes on architecture representation</u>

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.

<u>Equipment packages</u>

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

<u>Architecture flows</u>

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

3.4 Logical Layer of Bus Rapid Transit 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.

3.4.1 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.

3.4.2 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.

<u>Architecture flow triplets</u>

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.

<u>Properties of architecture flows triplets</u>

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.

3.5 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.

3.5.1 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.

3.5.2 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 (15) 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

4.0 REFERENCES

1. Levinson, H., et al., Transit Cooperative Research Program, Report 90, Bus Rapid Transit, Volume 1: *Case studies in Bus Rapid Transit*, Transportation Research Board, Washington, D.C., 2003.

2. Diaz, Roderick, B. Chang, M., Darido, G.; Kim, E., Schneck, D., Hardy, M., Bunch, J., Baltes, M., Hinebaugh, D., Wnuk, L., Silver, F., Zimmerman, S., *Characteristics of Bus Rapid Transit for Decision-Making*, Federal Transit Administration, U.S. Department of Transportation, FTA-VA-26-7222-2004.1, August 2004.

3. United States General Accounting Office, *Mass Transit: Bus Rapid Transit Shows Promise.* United States General Accounting Office, GAO-01-984, September 2001.

4. Kittelson & Associates, Inc., et al., "Cost and Effectiveness of Selected Bus Rapid Transit Components, Interim Report", Transit Cooperative Research Program Project A-23A, Transportation Research Board, July 2004.

5. Hess D., B. Taylor, and A. Yoh, "Light-Rail Lite or Cost-Effective Improvements to Bus Service? Evaluating the Costs of Implementing Bus Rapid Transit", *Journal of the Transportation Research Board*, Transportation Research Board, 2005.

6. Hensher, *A bus-based transitway or light rail? Continuing the saga on choice versus blind commitment.* Volume 8, No. 3, Road & Transport Research, September 1999.

7. Zimmerman, Samuel L., *Comparison of Bus Rapid Transit & Light Rail Transit characteristics.* SMART Urban Transport – 28 February, 2002.

8. United States General Accounting Office, *Bus Rapid Transit Offers Communities a Flexible Mass Transit Option.* United States General Accounting Office, GAO-03-729T, June 2003.

9. 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.

10. Levinson, H., et al., Transit Cooperative Research Program, Report 90, Bus Rapid Transit, Volume 2: *Implementation Guidelines*, Transportation Research board, Washington, D.C., 2003.

11. Cambridge Systematics, Inc., Parsons Transportation Group, Nelson/Nygaard Consulting Associates, Hausrath Economics Group, Montoya Communications, Inc., Carney Hammond Filmore, *AC Transit Berkeley/Oakland/San Leandro Corridor Major Investment Study (Volumes 1, 2 and 3)*. September 2002.

12. Website: http://msdn.microsoft.com/office/understanding/visio/

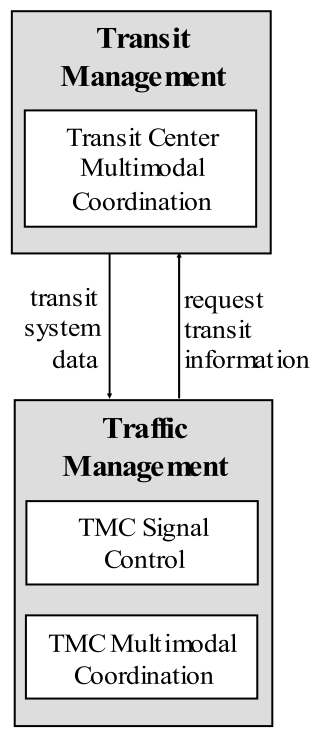
13. National ITS Architecture (version 5.1) website: http://www.iteris.com/itsarch/

14. Lo, H.K., M. Hickman, and S. 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.

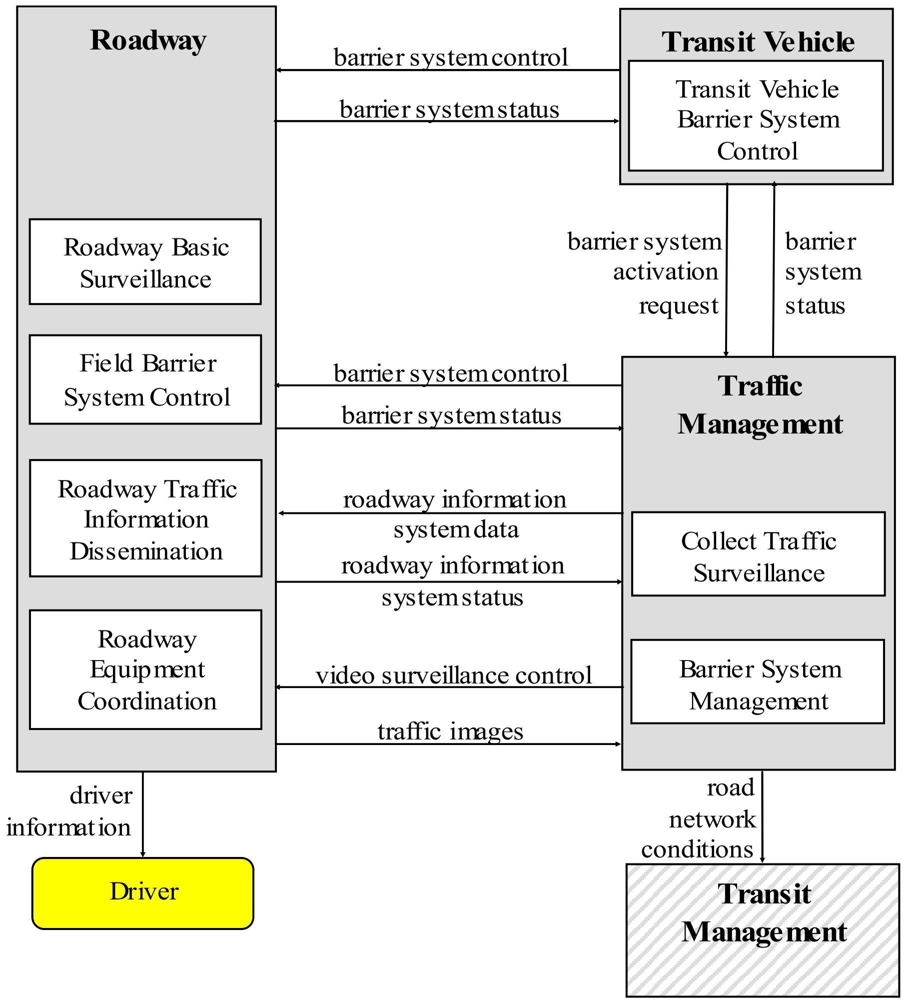
15. Turbo Architecture™, http://www.iteris.com/itsarch/html/turbo/turbooverview.htm. Accessed June 2, 2005.

APPENDIX A: FEATURE DIAGRAMS FOR BUS RAPID TRANSIT PHYSICAL ARCHITECTURE

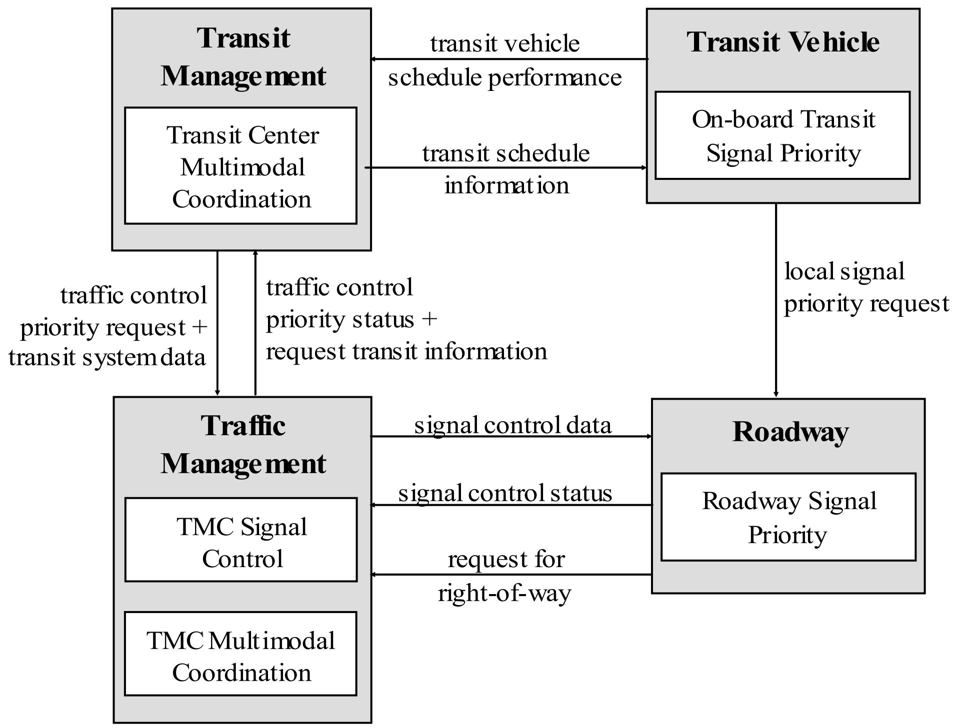
Feature diagram for "(1.1) – "Signal Timing/Phasing"



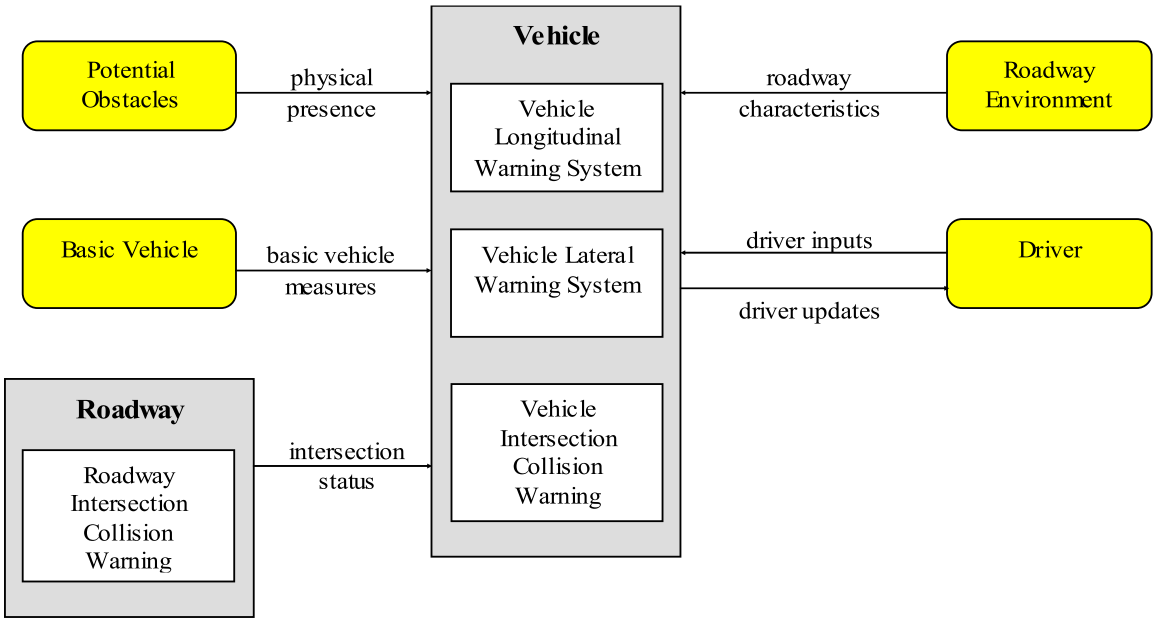
Feature diagram for "(1.2) – "Station and Lane Access Control"



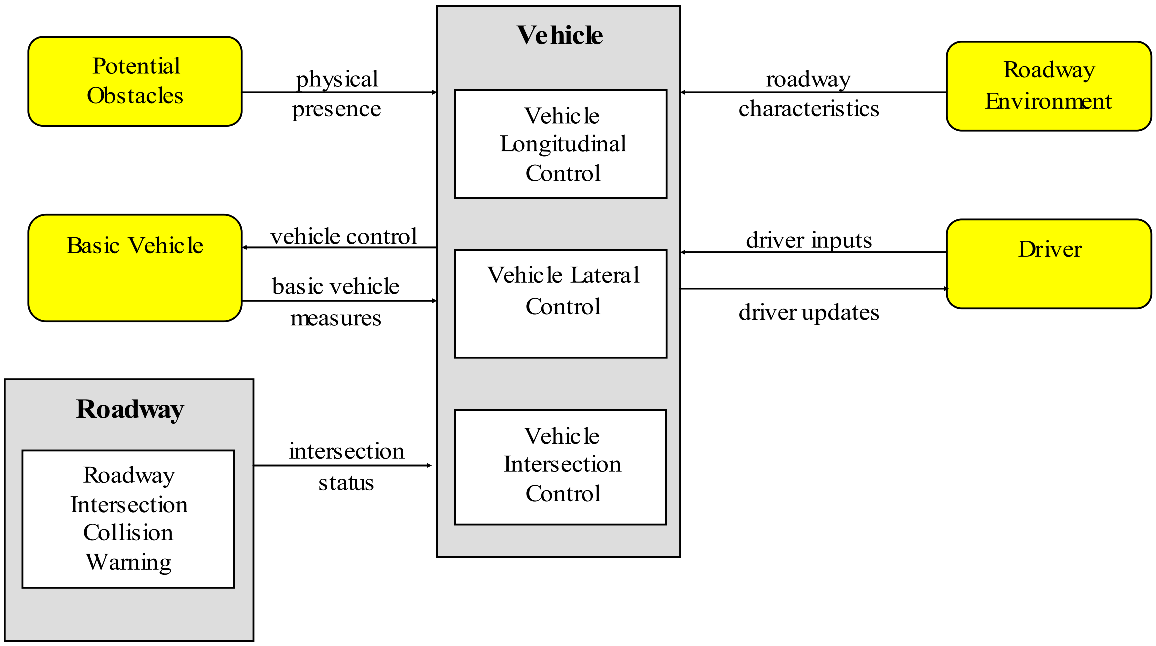
Feature diagram for "(1.3) – "Transit Signal Priority"



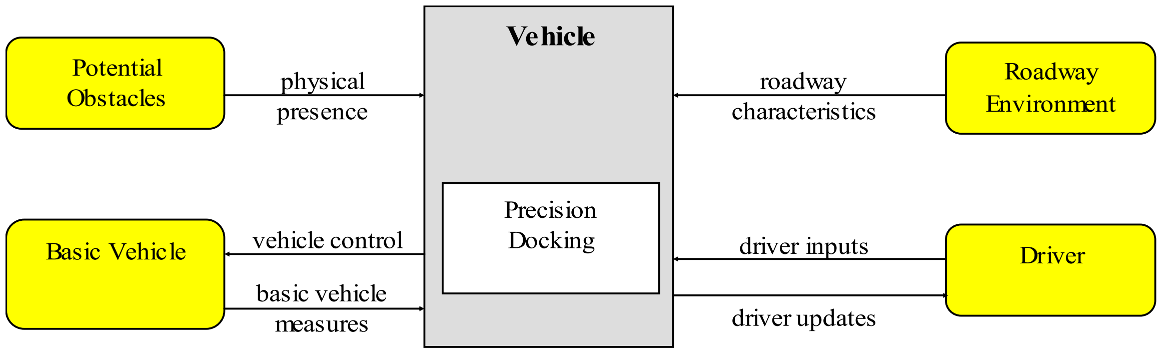
Feature diagram for "(2.1) – "Collision Warning"



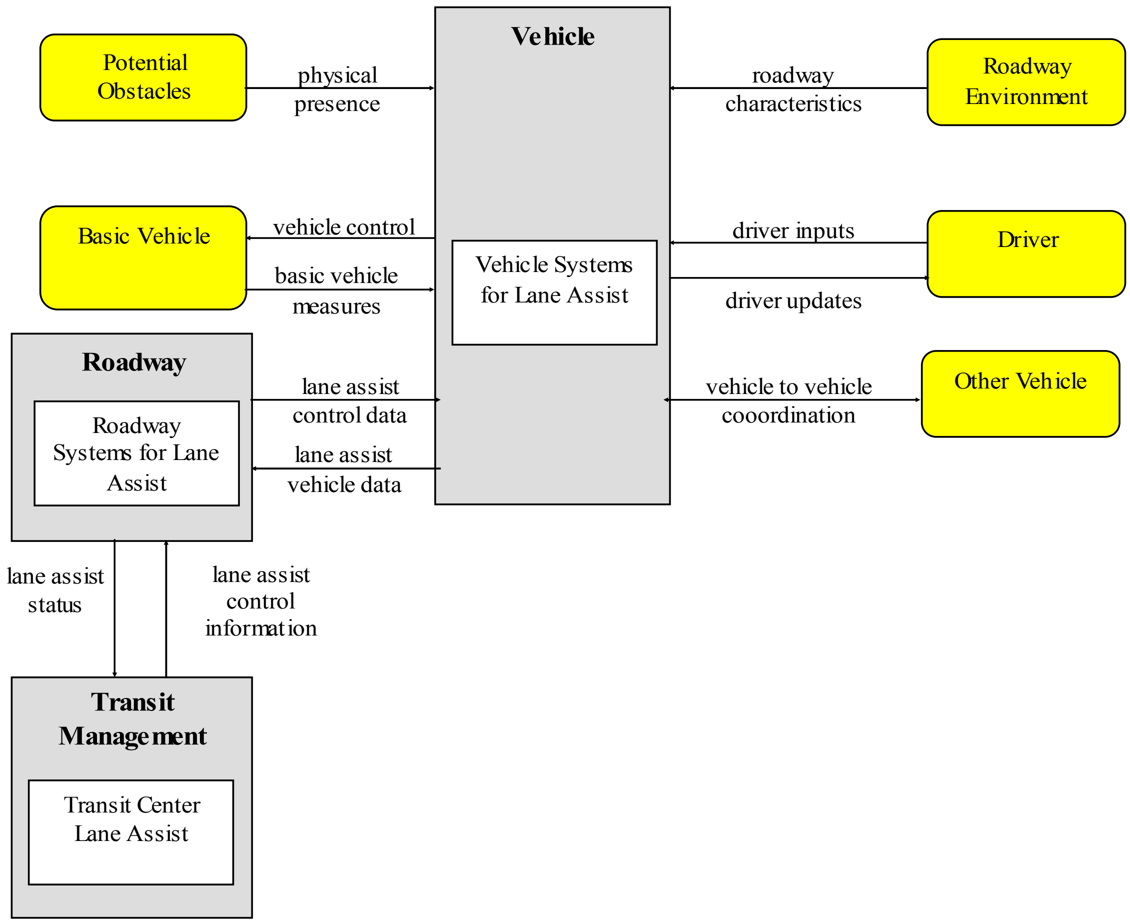
Feature diagram for "(2.2) – "Collision Avoidance"



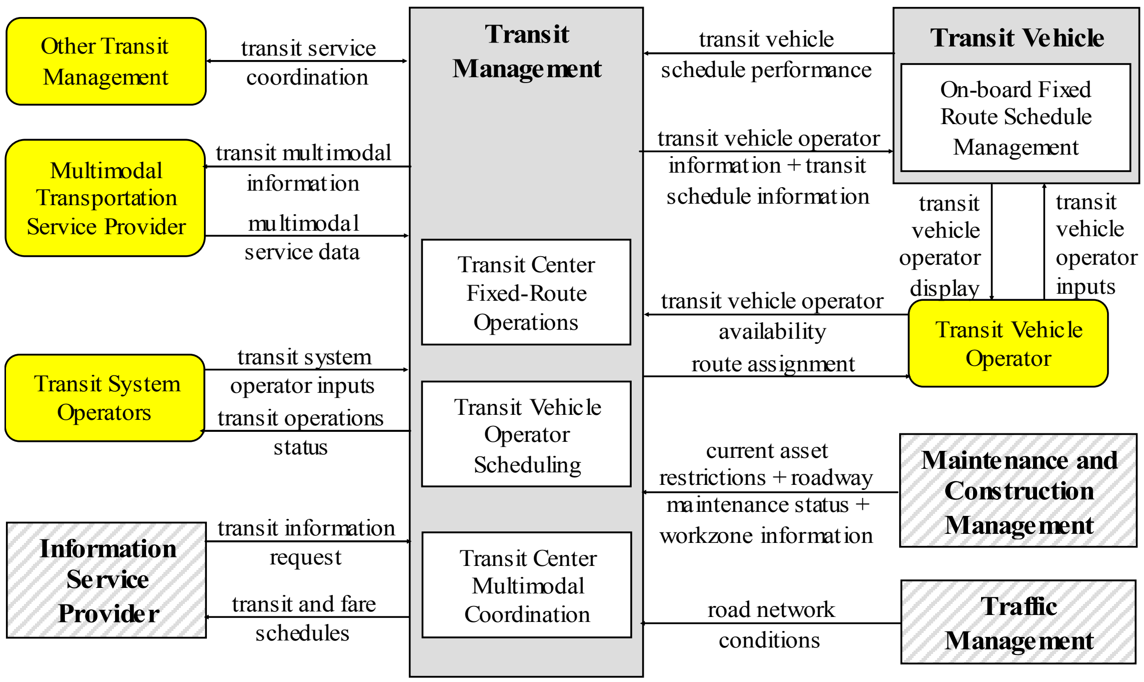
Feature diagram for "(2.3) – "Precision Docking"



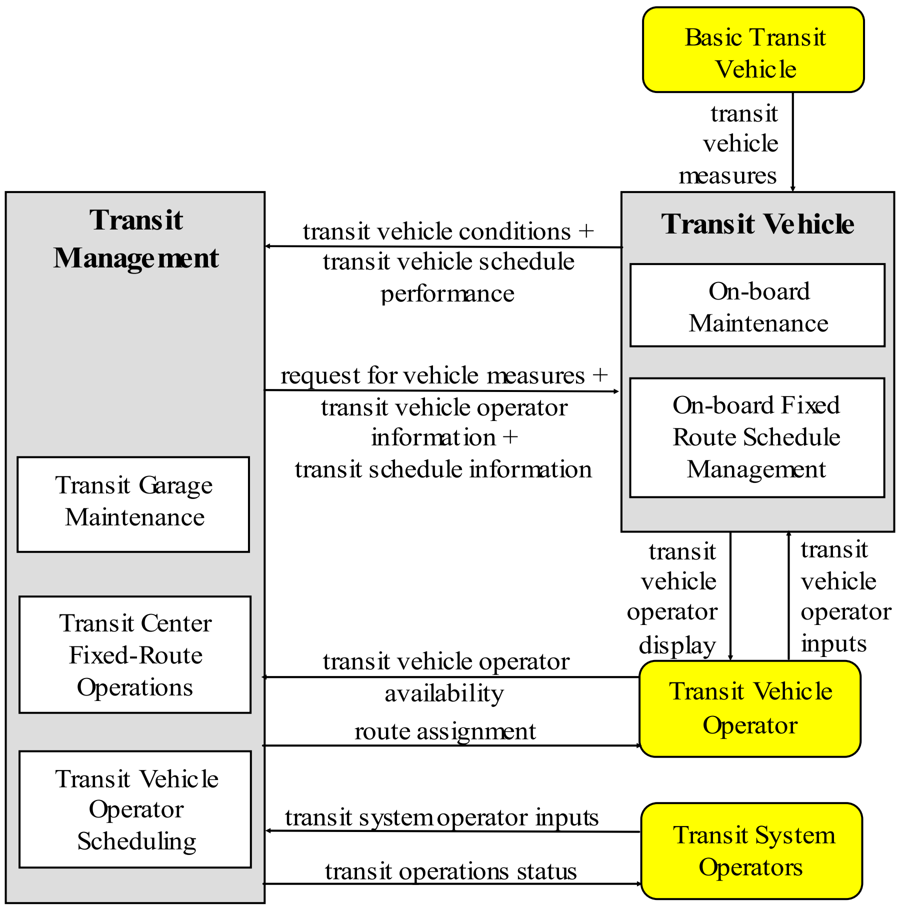
Feature diagram for "(2.4) – "Vehicle Guidance (Lane Assist)"



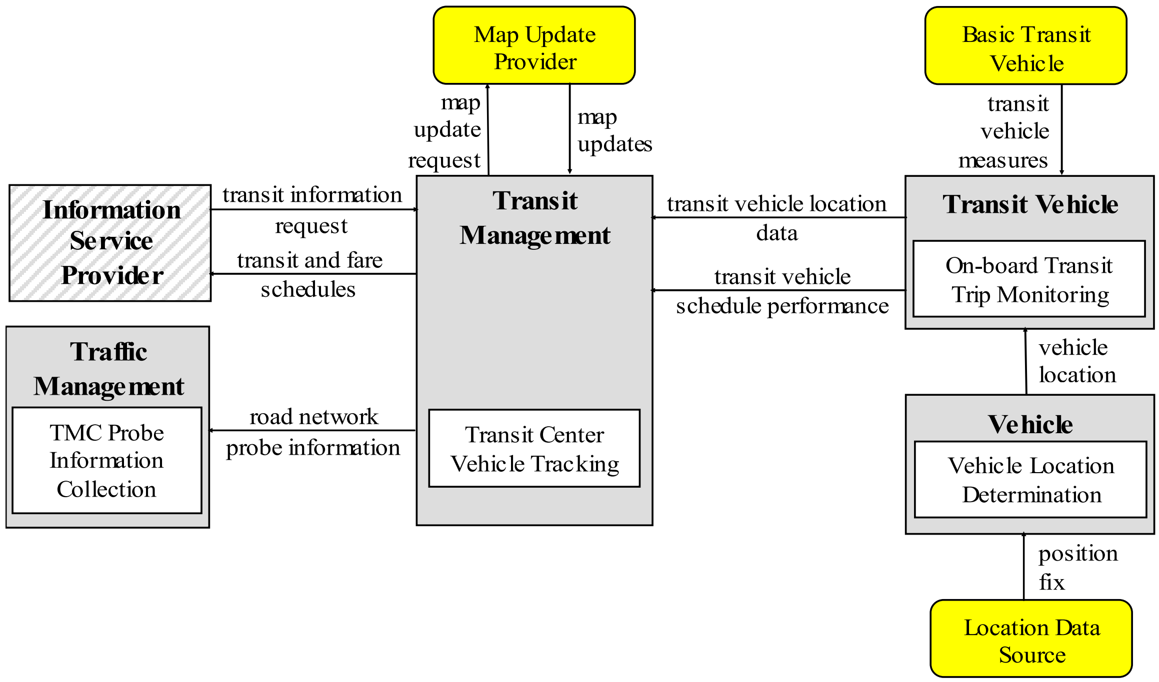
Feature diagram for "(3.1) – "Automated Scheduling Dispatch System (with Connection Protection"



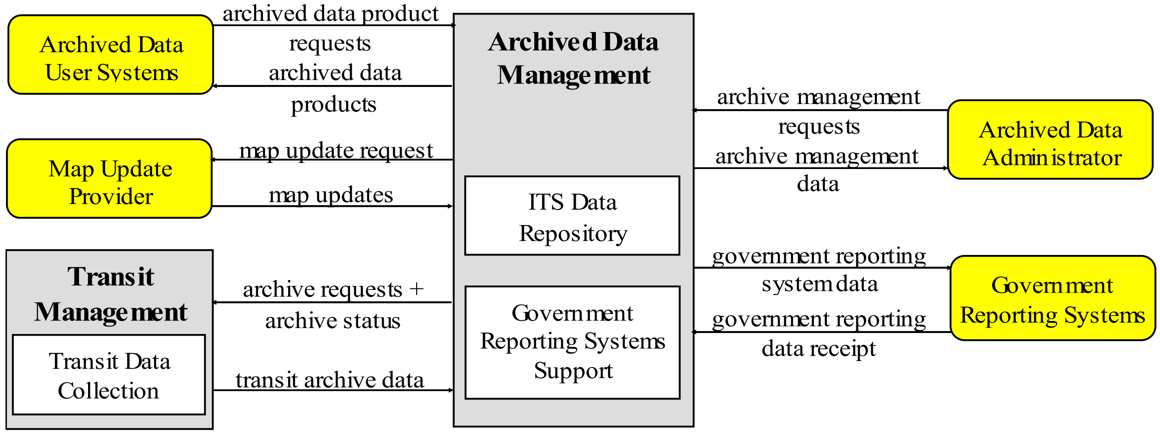
Feature diagram for "(3.2) – "Vehicle Mechanical Monitoring and Maintenance"



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

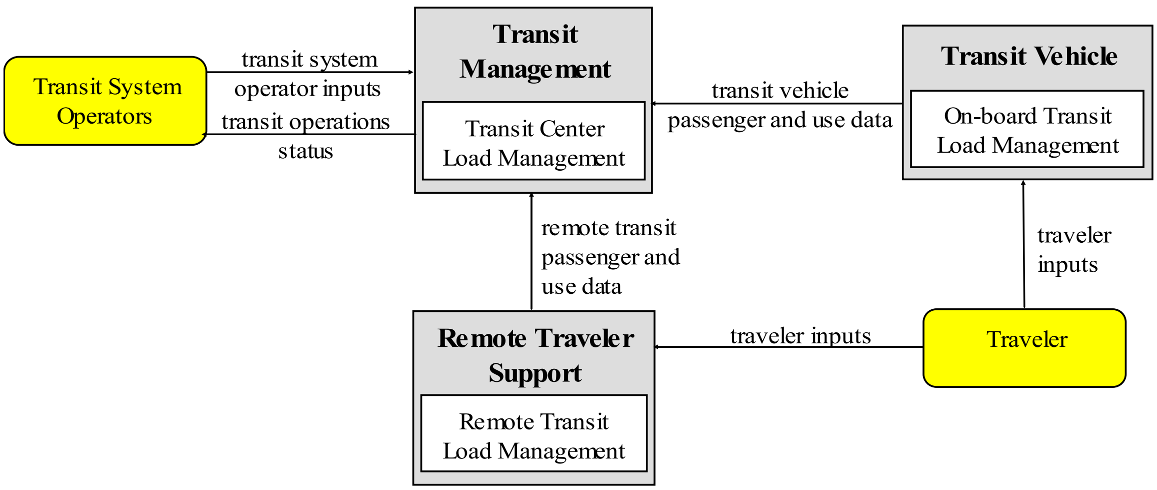


Feature diagram for "(3.4) – "Archived Data"

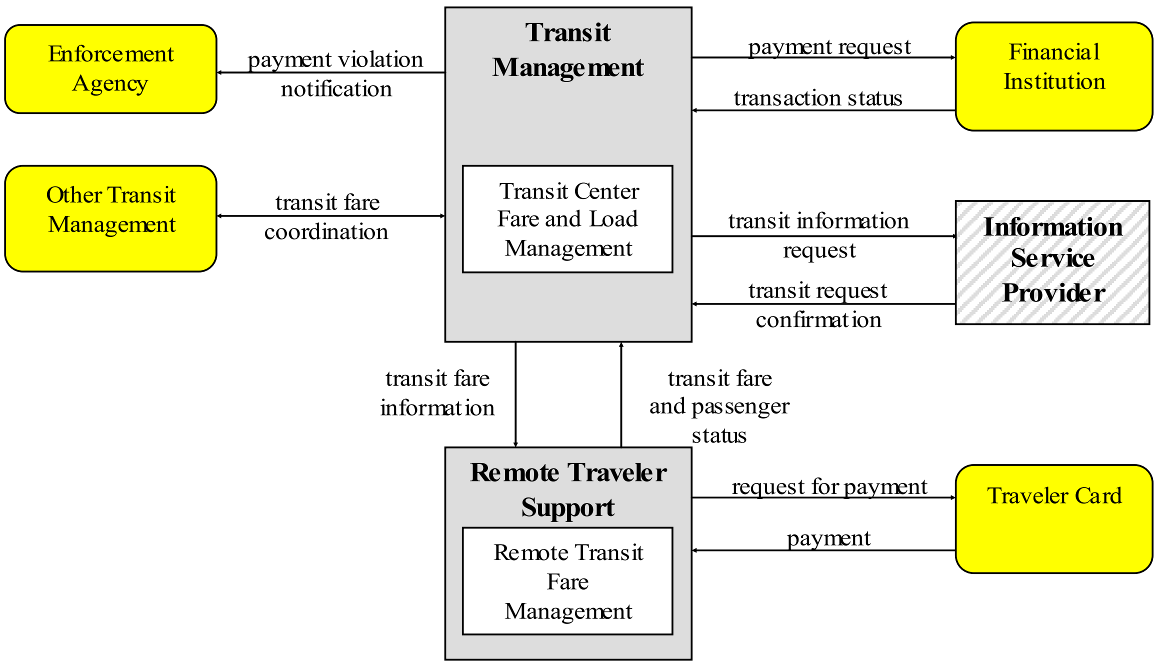


Feature diagram for "(3.5) – "Passenger Counting"

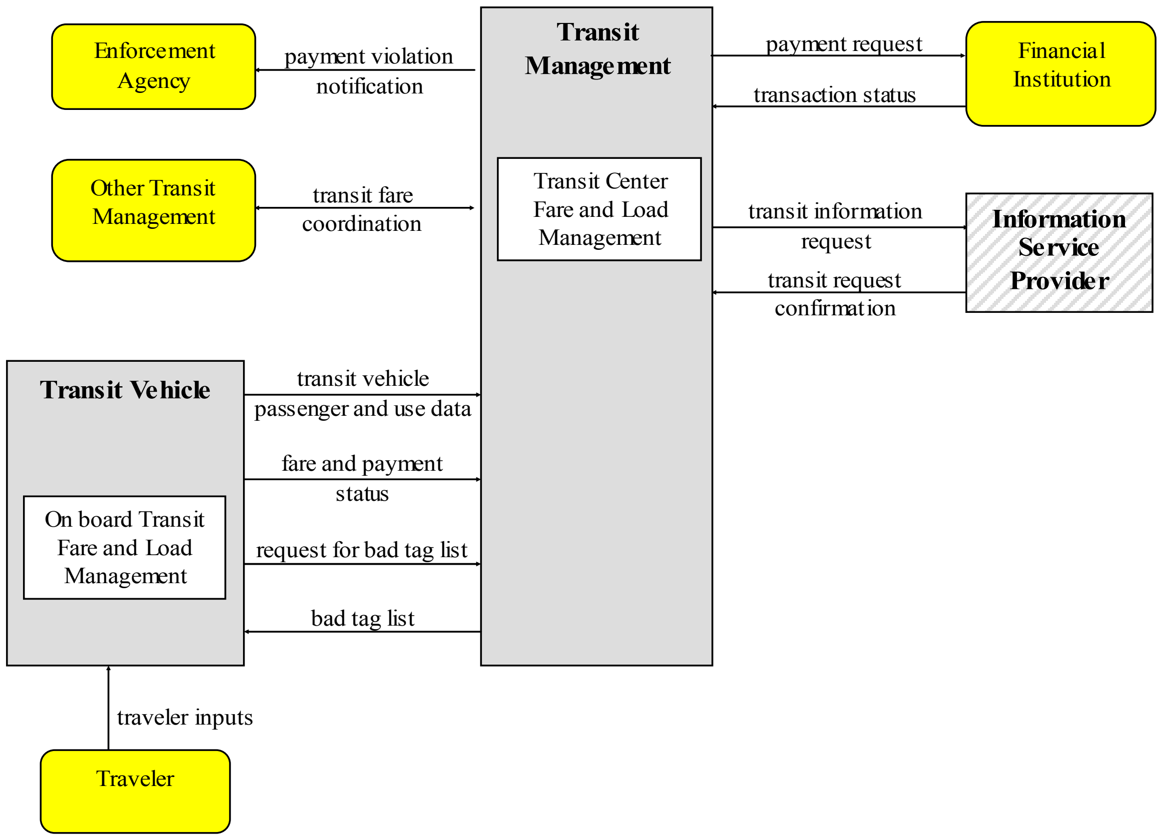
In this feature diagram, the specific task of passenger counting and load management has been identified. Additional entities, flows, and equipment packages would be added **if** passenger counting is included with fare payment.



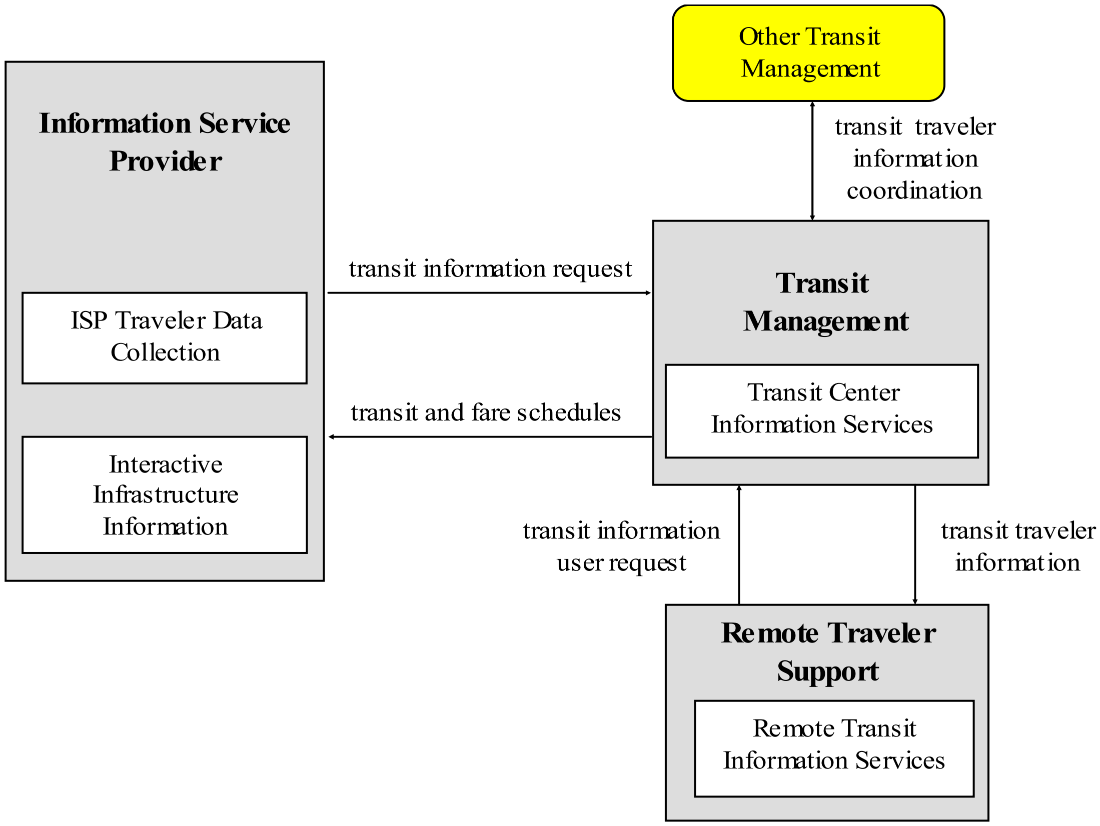
Feature diagram for "(4.1) – "Station-based Electronic Fare Payment"



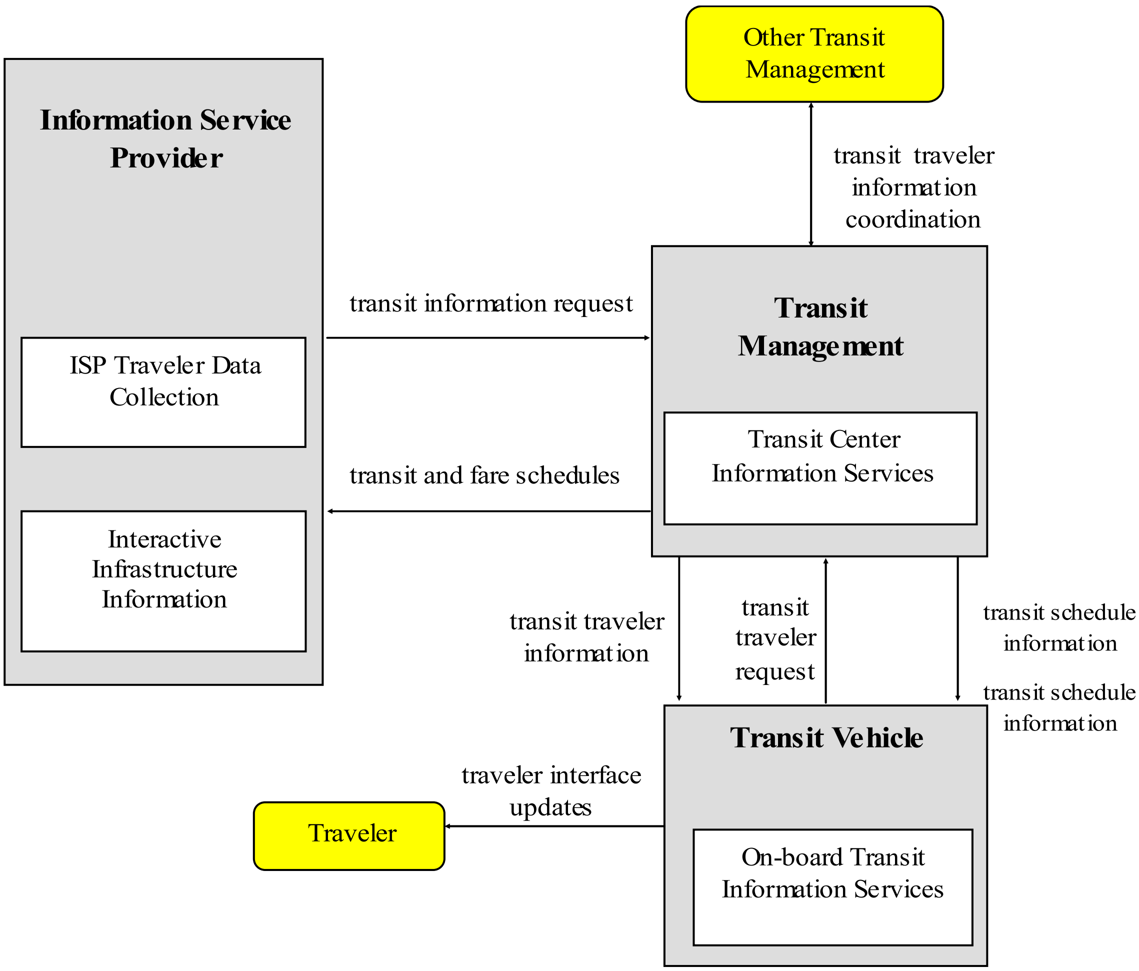
Feature diagram for "(4.2) – "Vehicle-based Electronic Fare Payment"



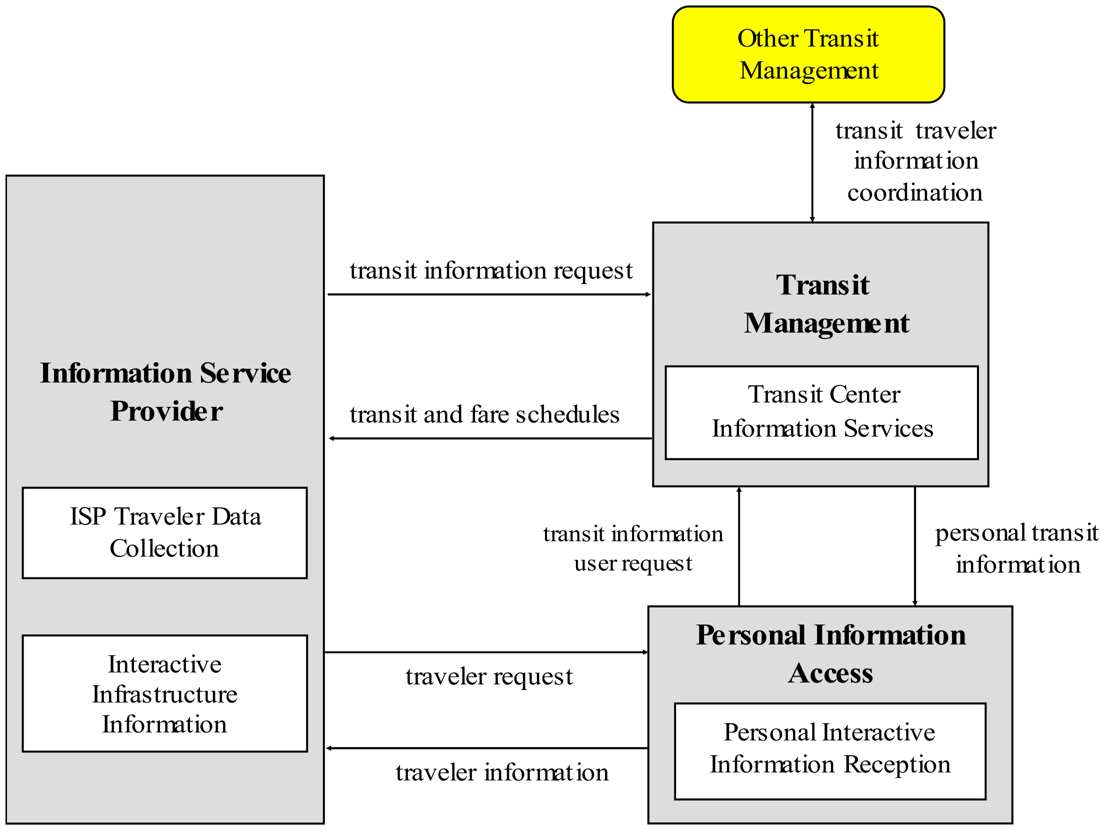
Feature diagram for "(5.1) – "Traveler Information at Stations/Stops"



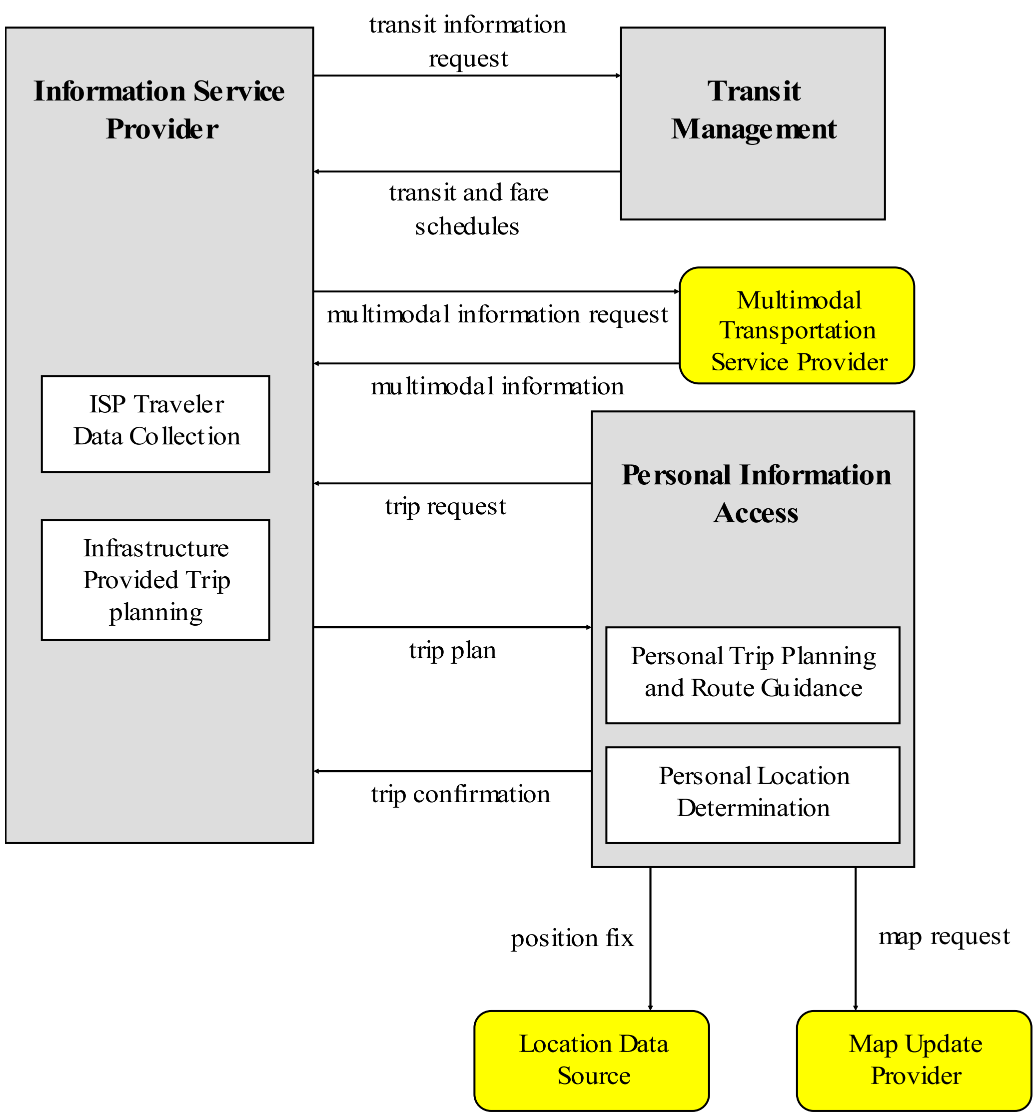
Feature diagram for "(5.2) – "Traveler Information in Vehicles"



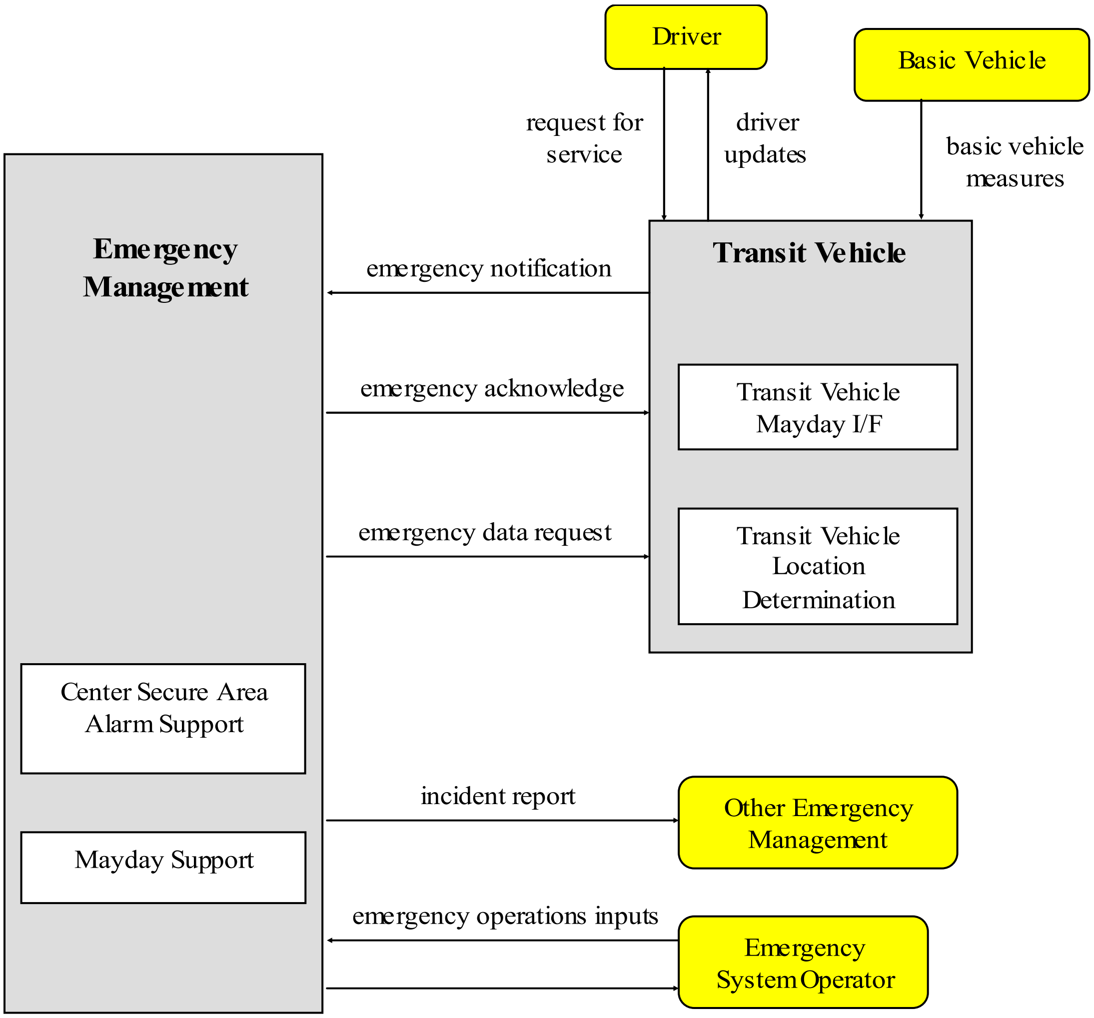
Feature diagram for "(5.3) – "Traveler Information on Person"



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"