Intelligent Transportation System for Bus Rapid Transit Corridors (ITS4BRT)

CLAUDIO L. MARTE, LEOPOLDO R. YOSHIOKA, JORGE E. LEAL MEDEIROS, CLEDSON A. SAKURAI, CAIO F. FONTANA
Polytechnic School
University of Sao Paulo
Av. Prof. Luciano Gualberto, 158, 05508-900, Sao Paulo, SP
BRAZIL
claudio.marte@usp.br, leopoldo.yoshioka@usp.br, jorge.leal@usp.br, akiocs@gmail.com, caio.fernando@unifesp.br http://www.poli.usp.br,

Abstract: Although Intelligent Transportation Systems – ITS applications are quite advanced for metro-rail, aviation and road modes of transportation, for BRT corridors there is a need of deepening the concepts in terms of the reference architecture, service group (domains ) and well established ITS functionalities. This paper focuses on determining how ITS systems can support the implementation of BRT corridors. It contains the definition of the main players directly involved or benefited by ITS. A proposal is also made for a Public Urban Transportation ITS architecture to be applied on BRT corridors. To do so, it was adopted a systematic identification process for ITS functionalities and its classification into groups of services. This approach can be used as a reference to improve ITS functionalities in future BRT corridors projects.

Key-Words: Intelligent Transportation Systems, Public Urban Transportation, Bus Rapid Transit, ITS4BRT Architecture, BRT, ITS.

1 Introduction
It is observed in Brazil a process of modernization of the Public Urban Transport - PUT to meet efficiently the needs of its users.

The relationships between the entrepreneurs, the managing agencies and society as a whole have evolved towards the establishment of partnerships that allow for the improvement of infrastructure and services related to economic and social progress achieved in the last two decades.

The lack and poor quality of PUT offered in medium and large cities of Brazil, together with factors such as economic growth and a policy of encouraging private transport, caused an undesired migration of PUT towards private transportation.

In this context of urban mobility deterioration there is a need for change. The BRT (Bus Rapid Transit) has emerged as a solution that can potentially completely change the current situation because it is one of the recommended options for medium capacity transportation systems. It is favored by cost-benefits trade-offs and by implementation periods versus deployment complexity [1].

These systems have become international references of PUT highly efficient, with quality and low costs. Several cities in the world use the BRT concept as the backbone for public policy for urban development [2].

BRT’s have high operating speed, greater capacity vehicles, segregated lanes, external billing, electronic payment, level boarding, priority signal control. It can be deployed gradually, initially at the most critical points or greater impact, evolving over time until it reaches its plenitude.

In order to allow BRT’s reaching its high levels of efficiency (less costs and higher reliability), safety and comfort for PUT users, it is essential to use advanced communication and information technology (CIT). This is a concept that clearly relates the evolution of transport services with the combined technologies of Intelligent Transportation Systems (ITS).

Although CIT tools are being applied in BRT systems, technical references allowing for a
This paper proposes a sub-architecture of ITS to support the operations of BRT systems (ITS4BRT). Initially it presents PUT service groups (domains) focused on BRT systems. In the following this, players interacting or benefiting from ITS services (ITS group of functionalities) are identified, and finally, it describes the ITS functions classified into groups (PUT service domains) [3] [4].

2 BRT Systems
This section will present PUT service groups (domains) with a focus on BRT systems and players interacting with or benefiting from its services, based on the analysis of these services.

2.1 Groups of Services of the PUT focusing on BRT systems
Based on the analysis of the processes concerning the BRT systems, it was identified seven groups of services in which ITS functionalities applies as follows:

- **Planning and Programming:** set of services involved – for example, to establish the level of the capillarity of the system and network range, types of services, attendance patterns and quality indicators and generation of service orders;
- **Operation Management:** set of services that allows to inspect, monitor and control, in real-time, PUT systems parameters and events, through the comparison with the schedules, intervening when necessary in order to conform the operation to the defined standards. Besides that, allowing the implementation of contingency measures in order to adjust adverse situations to established standards. Real time operations means being adherent to the computer systems and data communication available infrastructure;
- **Electronic Billing:** set of services responsible for the commercialization of credit, covering generation, distribution, validation and effective collection (ticketing) to compensation ("clearing"), enabling integration between different modes of transport;
- **Information to Users:** set of services responsible for distributing, in extensive updated and effective ways, static and dynamic information on the transport network, and on services available to users;
- **Prevention and Safety:** set of services responsible for providing greater security to the Traveler / Passenger / Driver, both for preventing the third parties actions for security purposes, as well as to prevent against operational risks for safety purposes;
- **Multimode Coordination:** set of services responsible for the coordination of transportation and transit systems, aiming at improving intermodal transfers services and prioritizing PUT traffic signal intersections;
- **Infrastructure:** it aims the continuity of operations, maintaining infrastructure and auxiliary services such as electricity supply, telecommunications, data processing, and others.

2.2 Actors
Presented below in alphabetical order are summarized definitions of main PUT actors, human and/or legal entities and/or systems interact in the use of ITS4BRT:

- **Commercialization agents and access control:** operating a vehicle and/or other PUT services connected equipment; responsible for credit trading, access control and assisting the entrance and exit of users/passengers.
- **Conductor:** operating a licensed vehicle and linked to PUT services.
- **Operational Controller (for PUT):** responsible for route schedules monitoring and controlling. Besides monitoring and controlling, its activities covers contingency measures, route and capacity modifications in real time operation. Modifications must take into account abnormal situations, such as vehicle breakdown, vehicle delay, necessary adjustment to balance exceptional demands etc.
- **Manager:** represents the state or public entities responsible for regulating and monitoring PUT services. It represents several other players, such as regulator, planner, scheduler and PUT monitor/supervisor.
- **Operator:** responsible for the PUT fleet operation, subject to Manager set rules, to the PUT services programming and guidance of the Operational Controller.
- **Passenger:** represents an individual, or a group in a vehicle, on a given trip.
Intermodal Service Provider: set of operators of other transport systems, such as: passenger airlines, ferry services and train service. It aims for an efficient movement of people through multiple modes coordination.

User: represents all the human entities that use, directly or indirectly, the services of the transportation system. According to time and situation, this player can be a pedestrian traveler, a Passenger, a driver, credit rates client companies or any other benefiting from services offered.

Traveler: any individual using transportation services.

3 ITS Functionalities
Listed below are ITS functionalities classified into service groups. There is a description and purpose indication of each of them.

3.1 Planning and Programming
Functionalities related to planning and scheduling.

3.1.1 Planning
Function allowing advance identification of demands, and modeling scenarios, evaluating alternatives, structuring actions and establishing routines and procedures.

Supported by ITS functionalities, Planning main duties and skills are to establish and define:

- **Service levels and quality of services:** accessibility, comfort levels, service integration levels, maximum waiting times (minimum frequency and commercial speed), quality/performance indicators and prevention levels.
- **Resources and infrastructure to available:** for route and line planning, service supply and economic-financial analysis (revenue distribution, cost analysis and companies economic-financial planning).

3.1.2 Programming
Based on Planning and depending on available resources, demand changing (daily and seasonally) and on other external aspects, PUT services are programmed, with the support of ITS tools. It aims at the best supply-demand relationship, with generation operational service orders (Daily Schedule). The results are quantity and types of vehicles per line, frequency, time travel, itineraries, the timesheet (timetable) and allocation of human resources (Driver, Commercialization Agent).

3.2 Operation Management
Measurement related functionalities (on-board information, stations, terminals and routes), fleet management, services management (travel, routes and capacity available), boarding platform doors automatic control, supervision on the use of the corridor routes (selective/exclusive) and autonomous guidance.

3.2.1 Measurement
It refers to functions associated with data (parameters) collection, processing and visualization on the vehicle and on the infrastructure (stations, terminals and pathways), necessary for the operation. They can be classified in two different types:

- **Embedded in BRT vehicle:** Monitor the usage level and performance of equipment, and how they are operated, contributing to the rationalization of equipment available, supply sizing, operation safety and comfort. Examples: monitoring (safety devices, opening/closing doors) and continuous measurements variables (position, speed, acceleration, occupation and engine/frame functions);
- **Associated with the infrastructure:** evaluate levels of on-board loads and traffic jams. Examples: the terminals and platforms - counting Users/Travellers on terminals and boarding platforms; counting and identifying vehicles on routes, speed measuring, advance signal and improper occupation of vehicle.

3.2.2 Fleet Management
Functions related to the ability to manage main inputs associated to providing PUT services, there being two types of them:

- **Maintenance and control:** obtaining, storing and processing information on performance conservation and attrition of parts, pieces and accessories, that help cost controlling, the equipment preservation, reduction of accidents and pollution, and failure failures. Examples: fuel consumption, vehicle mileage between failures, MTBF (Mean Time Between Failures),
• **Quality:** capture traffic safety, passenger comfort and vehicle-driver interaction data, equipment operation control, that will allow for evaluating driving of the vehicle and help establishing actions to correct or mitigate inadequate situation (for example: speeding).

### 3.2.3 Management of Services Provided

Functions allowing to monitor PUT operations performance and Control Operations Management. It monitors and controls, in real-time, elements of PUT systems, providing operation within principles and parameters predetermined in Planning and Scheduling.

These parameters refer to systems operating conditions which are subject to process interferences originated by various factors such as weather, public events, works, and driving action. Examples of functions: maintaining the service regularity and reliability; compare planned schedule with the actual operation performed; dynamically adjusting supply to demand (per station, terminal, line) and tailoring the operation to a situation not previously considered and taking into consideration resources available (this can include: allocation of extra trips or trip reduction due to demand variations.

### 3.2.4 Platform Doors Automatic Control

Function referring to the ability of automatic opening and closing of the station doors, and to supervising PUT corridors. This contributes to increase the commercial speed and the operational flow, synchronizing the doors station operation with the vehicle.

### 3.2.5 Monitoring of the use of the corridor pathways

Function related to supervision of the use and avoidance of the use of BRT lanes by unauthorized vehicles. It ensures the maintenance of operational performance of the corridor and the reduction of accidents.

### 3.2.6 Automatic Guidance

Function that allows for more precise and secure driving in narrow segregated lanes, without the need of driver intervention, except in emergency situations, thus eliminating the variations resulting from the different levels of driver skill.

Automatic guidance provides precise maneuvers in bus stops, increasing commercial speed and reducing the width of traffic lanes.

### 3.3 Electronic Billing

Below are presented the functionalities related to the generation and distribution of electronic credits; validation, collection (billing), passenger counting and clearing; integration and interoperability of systems and transportation equipment.

#### 3.3.1 Generation and Distribution of Electronic Credits

Generation of Electronic Credit is the function responsible for creating a set of credits to be used by the users for the payment of fees in the PUT. Each set of credits should allow its tracking throughout the usage process. A set of electronic credits may have an expiry date, allowing to verify unused credits during their validity period.¹

Distribution of Electronic Credits is the function responsible for the uploading electronic credits in the media to be used as payment on the PUT system.

#### 3.3.2 Validation, Collection (Billing), Count of Passengers and Clearing

Validation of Electronic Credits is the function responsible for verifying the validity and amount of available electronic credit being presented for tariff payment. It also designates the permission that the holder of that credit has to use it and the conditions under which that credit can be used. It is necessary for credit control by users benefited with some special conditions (for example, students paying reduced fares), which requires to some form of assured identification, such as biometric identification.

Collection of Electronic Credits, or Billing, is the function responsible for receiving electronic credits used by Passengers to pay their tariffs, following the validation process. It is desirable that this function presents some form of real time assured information backup, thus allowing to recover information related to amounts involved to that operation (for example,

¹PUT Users may require to recover their credits even after the expiry of the validity period, as they can be available through the electronic credit controlling agent.
batch identification of the credits mounts and associated users.

Passenger Count is the function responsible for accumulating information on the number of Passengers grouped by: vehicle or access control equipment (for example, a validator in a vehicle); on User type (paying or not), and, when applicable, the type of benefits related to users as well as the amounts paid for each of the identified groups.

Clearing is the function responsible by the distribution of the result of tariff amounts collected among all the PUT systems service providers. The rules to be applied on this distribution are previously agreed between the service providers and the PUT Manager.

3.3.3 Integration and Interoperability of Systems and Transportation equipment
Integration (modal and/or temporal) is the function allowing the use of a single media for fare payment, in a trip\(^2\) using one or more modes of transportation. Integration is a trend in metropolitan areas as a way to encourage the use of PUT.

Interoperability is the function that allows for the integration of different payment modes in PUT systems, being independent of the area covered and the systems used. The payment media of a system must be read by any other and allow, if necessary, the realization of tariff complementation and/or compensation. Interoperability requires the existence of more than one clearing house.

3.4 Information to Users
Indicated below are the functionalities related to the information made available: before the beginning of the trip for planning purposes; during the trip (or immediately before its beginning) of dynamic follow up; and post-trip.

3.4.1 Information available before the trip
Intended to assist the user in planning its trip. Allows the User to make decision on the most convenient (or example, faster or efficient) transportation mode and/or itinerary, based on knowledge of: route available, expected arrival time, the combination of transportation modes and of travel cost.

Most often these information refer to static\(^3\) aspects, such as local/intercity bus lines (routes, schedules, tariffs), intermodal terminals sites and parking lot locations, transportation services available (taxis, trains, urban/suburban, ferries), yellow pages\(^4\) (example: predictions of climate) and maps.

These information is offered to the User through various media, such as telephone, internet, radio broadcasting, mobile phones, smartphones, television and interactive public terminals (kiosks at strategic points). It may have different origins, other than the PUT system, such as tourist organizations, parks, urban transit operators and multimode (road, rail, waterway and airways).

3.4.2 Information during the course of travel
Functions that are intended to assist the Traveler/Passenger needing additional travel planning information. They usually are operational dynamic information\(^5\), aiming to assist the Traveler/Passenger to monitor and possibly to modify its trip (changing lines, paths), and providing guidance on:

- **Information to Traveler (Just Before of the Start of the Journey)** - for example: time of arrival of the next vehicle, or service suspension on a given line. The Traveler must receive this information when at the vicinity of or in a station, and can be circulated on the boarding platform.

- **Information to Passengers** - for example: next station, possible mode choices and connections, estimated arrival/travel time based on historical data and on actual situation, taking into consideration traffic conditions, climate, traffic congestions, operational incidents, accidents and public works.

There are several ways to circulate these information through special media such as voice messages, public address systems, Variable Message Signs - VMS\(^6\) located at strategic points in vehicles, stations, terminals and routes; special

---

\(^2\) A trip is associated with one origin and one destination

\(^3\) Unfrequently changing scheduled data

\(^4\) According to the American ITS Architecture, these are data related to entertainment such as information on tourism, leisure, culture and points of interest.

\(^5\) These are continuously changing briefings resulting of differences between the scheduled and the actual public transportation status

\(^6\) Variable Message Signs - VMS
radio equipment, mobile devices such as laptops or personal devices (mobile phones/smartphones) and browsers).

3.4.3 Post-Travel Information
Function aiming to provide information on travel history, such as customer services.

3.5 Prevention and Safety
The following are functionalities related to collision prevention, preventive driving monitoring, monitoring of vehicles (internally and its vicinity), of roads, stations and terminals; agglomeration/overcrowding control; public safety and emergency systems integration; automatic door control doors on stations or boarding, alighting and emergency.

3.5.1 Collision Prevention
Function performing the detection of vehicle approach to obstacles and to other vehicles, informing the driver by audible and visual alerts on the risk of collision.

3.5.2 Preventive Monitoring of Driving
Function aiming to monitor the driver's behavior with respect to drivability, being performed by cameras, sensors, acceleration and speed measurements.

Horizontal and vertical acceleration measures allow to check driver behavior in terms of vehicle speed in the curves and passing through holes and "bumps".

The stored data can be used to evaluate performance in each trip, during a period (day or month) and contributes to plan the training of Drivers, as well as the improvement of driveability (cost, safety, comfort).

3.5.3 Monitoring of vehicles (internal externally to it), of traffic lanes, stations and terminals
Function consisting on image monitors on-board vehicle, stations, terminals, bus stops, office boxes, entrances, platforms, roads and PUT vehicles parking lots, thus providing a greater sense of security to Users and Passengers.

This monitoring has different objectives, depending on the location of the cameras:

- **In the vicinity of the station:** preventing Users and public assets damage;
- **Inside the station:** helping to control overcrowding, inappropriate behavior, unauthorized sellers, harassment, revenue evasion, fraud investigation and also preventing Users and public assets damage;
- **Inside the vehicle:** providing more security to Passengers, Conductors, Agents of Commercialization against fraud, vandalism and crimes (internal to the vehicle), as well as more comfort on trips (focusing in front of the vehicle, allowing for the visualization of possible accidents);
- **On the segregated BRT track:** verifying the existence of elements that may endanger the vehicle, the Conductor and Passengers along the trip, such as obstacles and suspicious actions. Also preventing against invasion the pathway by unauthorized vehicles and pedestrians.

Alarms can be activated by Conductors / Users of the PUT and sent to the operations center. A panic button should be included in accident planning (for example: transmission of image and sound, activated due to the activation of the panic button.).

3.5.4 Control of Agglomeration / Overcrowding
Function monitoring the amount of Travelers and Passengers in stations and vehicles to determine the level of occupancy in order to avoid overcrowding and discomfort. A monitoring system by image can be used, as well as turnstiles and automatic access doors to limit the flow of Passengers. In panic situations the turnstiles at entrances/exits should provide a mechanism to facilitate the evacuation (free passage).

3.5.5 Integration with Public Safety and Emergency Systems
Function consisting of information voice and image sharing with security and emergency units, aiming at the prevention and treatment of critical situations, risks to Users and damage to the PUT system caused by offenders and criminals, vandals, weather or accidents. It can provide and use data

---

7 Radio Data System / Traffic Message Channel - RDS/TMC [ABNT/ISO 14819]
8 Georeferenced and indexed by events
from the Civil and Military Police, Rescue, Civil Defence and Fire Service.

3.5.6 Station Automatic Door Control
Function aiming to ensure the safety of Users boarding and alighting. It contributes to improving safety, minimizing risk of accidents involving Travelers while waiting at stations and platforms, as well as at the time of loading and unloading of vehicles. Can being used, for example, anti-crushing devices, positioning sensors, etc.

3.6 Multimode Coordination
Following are the functionalities related to integration between modes and semaphores management.

3.6.1 Integration between modes
Function allowing to coordinate agents operating different modes or transport (Intermodal Service Provider), and aiming to provide greater convenience at transfer points, and improving the PUT operation. Examples: subway to bus transfer, transfer from a system of greater capacity to another of lower capacity where there is a strong need for preparation or synchronism.

3.6.2 Traffic Light Management
Function favoring the circulation of PUT vehicles in street intersections. It can be implemented in two ways:
- Establishing communication channels between the operational PUT Systems Operations Control and the systems of Operational Control of the Urban Traffic Operations, seeking coordination between them;
- Establishing a dedicated short range communication between the vehicle and the semaphore controller.

3.7 Infrastructure
Set of functions enabling fast and precise problem identification, streamlining the solution through interventions of operation and corrective maintenance, triggering the charge and eventually effecting the activation of contingency plans. Allows critical systems, such as power supply, to operate at distance. Examples of equipment that can be monitored: turnstiles, automatic doors, vehicles, internal data networks, generators, air conditioners, computers, servers and other.

Another important function that can be added is the monitoring of external agents that can cause hazards or interference in the operation of the transport system, such as weather conditions such as rain and lightning, flooding of roads and stations.

4. Final Considerations
The services and functionalities currently available in the market are in various development and implementation stages. Some are already fully consolidated, some are still in initial phases, and others are in intermediate maturity, thus opening up a range of options, leaving to interested decision maker to evaluate such tools in order to assessing, for each situation, the feasibility of its application.

Although there are large benefits on ITS applications, there is still the need to fathom concepts and the feasibility of these BRT systems. Worldwide, there are not easily available papers on measuring, verifying, and analyzing costs and benefits associated with applications on specific BRT systems. Thus, future studies may focus on cost-benefit analysis for investment decisions in order to ensure conscious and responsible decisions.

5. Conclusions
The road urban transport sector now faces the challenge of exploring uses of the ITS in BRT systems implementation.

This paper aims to systematize an architecture of ITS to PUT, with emphasis on BRT systems, identifying players, service groups and ITS functionalities.

It is desired that this systematization can contribute to better design future BRT systems with the most appropriate application of ITS functionalities available.

Acknowledgements
The authors wish to tanks the following ITS Technical Commission of ANTP (National Association of Public Transport) members: André Dantas, Denis Balzana Azevedo, José Carlos Sepulcre Neto, José Mauro Marquez, Júlio Grillo, Sérgio Antonio Pavonatto Cerentini and Valeska Peres Pinto.
References: