

Intelligent Public Transportation Systems: A Review of Architectures and Enabling Technologies

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Abstract — Intelligent Public Transportation Systems (IPTS) are a subsystem of Intelligent Transportation Systems (ITS), which aim to control public transportation networks, to maintain their performance, and to provide users (passengers and decision makers) with up-to-date information about trips and network operating conditions. To reach these aims, IPTS rely on several technologies that can be embedded within different control architectures. This paper introduces IPTS components and technologies, identifies the different types of data captured from the transportation network and exchanged between IPTS components, and shows ways to integrate technological components and data within IPTS architectures. A section is dedicated to review architectural design of some developed IPTS to control public transportation networks. Finally, some challenges are discussed and further research directions are highlighted.

Keywords — *Intelligent Transportation Systems; public transportation; technologies; architectures;*

I. INTRODUCTION

City life and urbanization have introduced mobility problems and raised issues concerning transportation of both people and goods. Public transport (also known as public transportation or public transit) refers to shared passenger transport service, which is available for use by the general public. Public transport modes include buses, trolleybuses, trams and trains, rapid transit (metro/subways/undergrounds etc.) and ferries. Public transport between cities is dominated by airlines, coaches, and intercity rail. High-speed rail networks are being developed in many parts of the world.

Despite the spread and success of implementing public transport networks, it is becoming more and more difficult to guarantee high levels of quality of service for users, for example in terms of punctuality and frequency of shuttles. This difficulty is due, on the one hand to the continuous urbanization, which makes transportation networks grow in size and, on the other hand, to the ever increasing complexity of managing transportation networks. Implementing new intelligent decision support and control systems is becoming necessary both to manage public transportation networks, and to assist authorities, who are investing in new means, infrastructures, information and control systems to improve mobility in cities.

Intelligent Transportation Systems (ITS) have been introduced to take full advantage of the existing public transportation infrastructure, and to enhance its efficiency, effectiveness and attractiveness. ITS are defined as the application of advanced communication systems, information processing, control and electronics technologies to improve the transportation system and to save lives, time and money [1].

ITS for public transportation, also called Intelligent Public Transportation Systems (IPTS)[2], rely on many innovative technologies, which fostered their development and implementation. For example, Geographical Information Systems (GIS) help in designing new routes and shuttles. Automatic Vehicle Location Systems (AVLS) rely on Global Positioning Systems (GPS) to localize transportation means and vehicles. Traveler Information Systems (TIS) provide users with real-time information about the state of the network. IPTS also allow for the integration of Decision Support Systems (DSS), which suggest regulation strategies and control decisions to maintain the performance of the network. All of these information systems and technologies share, process and exchange several types of data provided by different detection devices, and advanced technologies, such as global positioning satellites (GPS) and sensor networks.

Although a few works, such as [3] and [2], discussed technologies used in the field of public transportation network management, these works are limited to the presentation of technical aspects and only present technologies to capture data from the network. These works do not discuss how technologies and information systems can be integrated within IPTS architectures, what kind of data and how this data can be exchanged through the different IPTS subsystems to achieve the common and ultimate goal of controlling the transportation network and optimizing its performance.

Therefore, the aim of our paper is to fill this gap by presenting an updated review of innovative technologies used in IPTS. We particularly highlight how required data is captured. We describe how integration between IPTS data and components is achieved within architectures that are able to suggest suitable regulation strategies and control decisions to reach the ultimate goal of controlling the transportation network and optimizing its performance. Therefore, the purpose of this paper is not to analyze existing IPTS but rather to present its different components, architectural layers, and

enabling information and communication technologies. The paper is organized as follows: Section 2 introduces the intelligent public transportation systems (IPTS). Section 3 presents different communication and information technologies integrated in IPTS. Section 4 reviews works suggesting architectures to integrate these technologies within Intelligent Public Transportation Systems (IPTS). We conclude by discussing some challenges and highlighting further research directions related to IPTS design and implementation issues.

II. ITS FOR THE MANAGEMENT OF PUBLIC TRANSPORTATION NETWORKS

The European Union (EU) Directive 2010/40/EU defines ITS as systems in which information and communication technologies are applied in the field of road transport to manage infrastructure, vehicles, users (passengers and decision makers), traffic flows and mobility within cities, and to interface with other modes of transport. According to this definition, ITS are made of several subsystems including:

- Advanced Traffic Management Systems: ATMS act on traffic signals to control traffic flows and to enhance mobility in cities.
- Advanced Rural Transportation Systems: ARTS focus on traffic management in rural environments.
- Commercial Vehicle Operation Systems: CVOS monitor commercial vehicles, trucks and vans using satellite based navigation systems.
- Advanced Public Transportation Management Systems (APTMS), also called Intelligent Public Transportation Systems (IPTS) [2] or Advanced Public Transportation Systems (APTS) [4]: these systems rely on a set of advanced communication, information processing, control and electronics technologies to control public transportation networks.

In this paper, we only focus on Intelligent Public Transportation Systems, which we refer to as IPTS. Our purpose is to present technologies used in IPTS and to discuss architectural aspects to show how these technologies can be integrated within a control system. IPTS are intended to analyze and evaluate the status of transportation networks, to detect disturbances (such as accidents, technical problems, traffic congestion, etc.) that can affect prescheduled timetables and make them deviate from their expected performance and/or behavior, and to suggest efficient regulation strategies and control decisions to maintain the performance of the network. IPTS provide users with up-to-date information about the status of transportation networks. The development and implementation of IPTS improves the quality of service of public transportation networks and promotes the use of public transportation means in cities, thus contributing to reduce congestion and pollution and to improve mobility. Several measures of effectiveness of IPTS were proposed and detailed in [5]. These measures include indicators about safety, mobility, efficiency, productivity, energy, environment, and customer satisfaction. To reach high levels of Quality of Service, IPTS rely on a wide variety of technologies and applications that can be grouped in five main categories:

1. Automatic Vehicle Location Systems: AVLS provide decision makers with real-time information about vehicles, such as location, speed and direction of vehicles, and information about delays due to disturbances, such as traffic congestion, accidents, bad weather conditions, or road repair work.
2. Traveler Information Systems: TIS provide passengers with real-time information about the operating conditions of the network, such as scheduled shuttles and arrival and departure times of vehicles.
3. Automatic Passenger Counters: APC count on-board passengers and those waiting for vehicles at stop stations.
4. Geographic Information Systems: GIS allow an instant mapping and follow up of the progress of vehicles on their routes. GIS also allow for the design and implementation of new routes and shuttles.
5. Decision Support Systems: DSS assist decision makers in controlling the transportation network by suggesting control decisions and regulation strategies when unexpected events or deviations from expected performance and/or behavior occur.

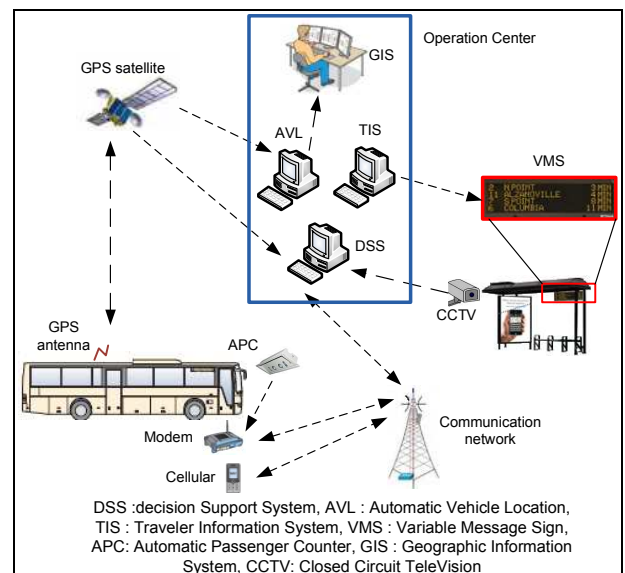


Figure 1. Intelligent Transportation system

III. TECHNOLOGIES FOR IPTS

Several technologies allow IPTS to retrieve data from multiple sensor systems, to supervise and control the transportation network. Information and communication technologies are widely used in IPTS. Vehicles, stations, operation centers and other transportation infrastructure are equipped with recent technologies including tracking systems (such as GPS or radio navigation), infrared beams, wireless equipment and communication infrastructure (GSM and GPRS networks). These communication systems enable vehicles, passengers and decision makers to interact with the different components of the IPTS as illustrated in figure 1. These technological devices enable decision makers to monitor the network performance and to make suitable control decisions to

insure good operating conditions. This section identifies and presents information and communication technologies integrated within an IPTS.

A. Automatic Vehicle Location Systems

Automatic Vehicle Location Systems (AVLS) provide information regarding the exploitation of a transportation network. In the scientific literature, such systems are often referred to under several names, such as Automatic Vehicle Monitoring Systems AVMS [6], Automatic Vehicle Location AVL [7], Exploitation Aid System EAS [8-9] or Exploitation Support System ESS [10]. In this paper, we refer to these systems as AVLS. Such systems give a global overview of a transportation network and provide real time information through the use of several vehicle location and tracking technologies. Data provided by AVLS includes updated states of timetable execution, delays, and vehicles in advance. The implementation of AVLS has greatly facilitated the task of decision makers because AVLS can monitor real-time operation of a public transportation network and process a very large amount of network information.

One of the first forms of vehicle tracking technologies being used was the ground based radio system (GBR). It determines location based on the reception of signals and the associated timings from various transceivers. As reported in [11], the accuracy of this system is not consistent especially in urban areas as they are highly susceptible to radio frequency and electromagnetic interference from power lines and substations in urban and industrial areas.

Signpost and Odometer were also among the primary technologies used for vehicle tracking. With this technology, receivers are placed on vehicles, while transmitters are placed along vehicle routes. Vehicles transmit a low-powered signal as they pass by these transmitters, and the mileage is noted. AVLS based on this technology have some drawbacks. For example, Signpost transmitters require periodic maintenance (to replace battery for example). Furthermore, the creation of new routes requires the placement of new transmitters. Due to limitations of GBR and Signpost/Odometer technologies and with the development of applications in electronics and digital communications, Global Positioning Systems (GPS) became the most popular systems for vehicle tracking [12]. GPSs are space-based satellite navigation systems that provide location and time information in all weather, anywhere on Earth. This system was developed by US department of defense to serve the military need to locate vehicles. The system uses a total of 24 satellites [19]. In transportation systems, vehicles are equipped with a GPS antenna, which communicates with four or more satellites to give the location of the vehicle.

Galileo is another global navigation satellite system developed by the European Union to provide high-precision positioning independently from the American GPS. Some European IPTS use this navigation system such as CIVITAS [14]. Satellite based navigation systems give a good precision only with the presence of line of sight between the receiver and satellites. Otherwise, the signal will be attenuated and, thus, vehicles cannot be tracked. Due to this limitation, RFID technology is also used as vehicle tracking systems [15].

Other technologies are integrated in IPTS to locate vehicles in the network. For example, Closed Circuit TeleVision (CCTV) are coupled with image processing techniques to monitor vehicles in the public transportation network of London by the use of 2000 cameras installed in the routes and stations [16].

B. Traveler Information Systems

ITS for public transport integrate technologies to provide information to travelers or to operation centers. A "Traveler" is defined as a person who changes location by any transportation mode. Some authors also consider vehicle drivers as travelers [17], while others only consider passengers as travelers [2]. The main goal of Traveler Information Systems (TIS), also referred to as Real-time Passenger Information System RTPIS [18], is to provide real time information to travelers about the state and operating conditions of the network, such as vehicles arrival time, and assist them to allow informed pre-trip and en route decision making.

According to Adler and Blue [19], two generations of TIS exist. The first one is the Variable Message Signs (VMS) that provides information about vehicles. VMS are used in stations to provide travelers with important information about the network, such as vehicle waiting time or presence of incidents. Data are sent to VMS via communication infrastructure, such as GSM or wireless network [20]. The second generation is the Advanced Traveler Information System (ATIS), which uses recent technologies, such as internet or mobile phones, to provide information about traffic conditions, route guidance and en route traveler information in a more real time manner.

Several TIS were developed to assist travelers in making pre-trip and en route travel decisions, such as Intelligent Traveler Information Systems ITIS by Adler and Blue [19], Path2Go by Zhang *et al.* [21], and work by Praveen *et al.* [22]. RAPID is another commercial TIS developed by Sigtec¹ company using SMS, web and street displays. RAPID solution incorporates an AVLS system to send up-to-date information about vehicle arrival times to passengers. To provide more efficient data on vehicle travel or arrival time estimates to passengers, TIS are based on AVLS [23]. For example, SITREPA [24] is an IPTS which integrates an AVLS and TIS and tested in the city of Leiria (Portugal). As other IPTS, SITREPA acquires data from AVLS and provides information to satisfy the needs of different actors in the public-transportation system as passengers or decision makers.

C. Automatic Passenger Counters

Automatic Passenger Counters (APC) are systems that count on-board passengers and those waiting for vehicles at stop stations. Such information can be used to analyze the global performance of the transportation system [25]. It can be used to calculate average vehicle travel speeds and dwell times [26]. APC can interface with AVLS to provide transit agencies with transit origin-destination data [26]. The first generation of APC was based on manual ride checks to collect the necessary data on boarding and alighting activities. Recently, communication technologies are widely used to develop more

¹ <http://www.sigtec.com>

efficient APC. Such technologies include treadle mats and infrared beams, which recognize passengers when the beam is broken. Computer imaging is also used, which is based on intelligent image detection systems to recognize and count on board passengers [16]. [27] evaluated the performance, in terms of accuracy and precision, of on-board camera and other APC systems. They reported that camera systems are more precise than on-board ride checkers.

D. Geographic Information Systems

Geographic Information Systems (GISs) capture, store, manipulate, analyze, manage, and present all types of geographical data related for example to vehicle route design [27]. The first task of a GIS is to code data collected by tracking systems, such as GPS or Galileo systems (see subsection A). Thus, the connection of GIS to GPS allows instant mapping and follow up of the progress of vehicles on their routes, and localization of disturbances on the transportation network [29]. In many ITS, GIS is also used for analyzing the traffic flow [30], for evaluating and ranking vehicle service [31] and for transportation network design [32]. In the last few decades, researches focused on automating the route-planning process using GIS technology [33]. Some commercial GIS software, such as ArcGIS [34] or MapInfo [35], exist and can be used to develop digital maps and to realize basic GIS functions.

E. Decision Support Systems

Decision support systems (DSS), also called Scheduling and Dispatching Software [36], have two main objectives: timetable establishment and control strategies building.

The first common objective of DSS is the establishment of efficient transportation timetables that satisfy passengers, who expect high levels of quality of service, in terms of timely and regular shuttles. Transportation timetables are initially established taking into account information about forecasts of traffic conditions, rush hours, demand for transportation, etc. [6]. Several works use either exact [37] or heuristic [38] methods to determine timetables that optimize one or several objectives, such as minimizing total trip time or cost [39], minimizing passenger waiting time, or minimizing passenger in-vehicle time [38].

However, during the execution of pre-established timetables, disturbances may appear that can make these timetables deviate from their expected course, causing them either to be delayed or to become obsolete [40]. When they occur, such disturbances like accidents, traffic congestion, absence of personnel, bad weather conditions, etc., degrade the expected performance of the transportation network, decrease its expected quality of service, yield to passenger dissatisfaction, and may cause the appearance of congestion at stations or on transportation pathways. Consequently, decision makers have to monitor the execution of pre-established timetables, and to make reaction decisions in order to bridge the gap between pre-established timetables and really executed ones. The second objective of DSS is to maintain the performance of pre-established timetables at acceptable levels. DSS have to analyze incoming data from Automatic Vehicle Location systems (AVLS) and Automatic Passenger Counters

(APC) in order to detect serious delays of vehicles. When such is the case, DSS have to suggest suitable control decisions and regulation strategies to eliminate or at least reduce deviation from predefined timetables. Several works suggested control decisions; including holding strategies [37-49] and stop skipping strategies [39]. DSS can receive information from special equipment, such as panic buttons. In some cities like Washington DC in USA [41] or La Rochelle in France [42], stations are equipped with panic buttons that can be activated by passengers, operators or drivers to alert passengers and operation centers to take immediate action.

According to [43], DSS must integrate three main phases:

- Diagnostics phase: it consists in monitoring and analyzing the transportation network to detect disturbances, anomalies and deviations from expected performance and/or behavior using AVLS.
- Decision construction phase: the system suggests control decisions and regulation strategies for the detected disturbances, anomalies and deviations.
- Decision evaluation phase: control decisions and regulation strategies are evaluated using simulation [44] or exact methods [45] to select the best alternative to be applied.

Several studies were proposed to design DSS to control public transportation networks, such as TRSS [6], MASDAT [46], SMAST [47], and systems by Masmoudi *et al.* [9], Tlig and [48], and [49]. Such systems receive information from AVLS, TIS and APC via radio or other communication technologies, such as cellular phones or modems.

IV. IPTS ARCHITECTURES

Several studies were proposed to design IPTS architectures. Davidsson *et al.* [50] pointed out that, at least until year 2005, 64% of the existing research focused mainly on design issues and architectural aspects. These architectures integrate a variety of information systems that receive data from sensors. As illustrated in figure 2, these data concern vehicles (vehicle location, routes, direction, next station, and accidents), passengers (waiting or on-board passengers) or other incidents (technical problems). These data are sent to IPTS subsystems such as DSS or TIS using communication networks as GSM, Modem or Wireless networks. The DSS analyzes received data to monitor the execution of pre-established timetables and make reaction decisions in order to bridge the gap between pre-established timetables and really executed ones.

Most of developed IPTS implement Interactive Decision Support systems, considered as the core of an IPTS, integrating the decision maker in the decision loop (figure 2). With respect to the integration of decision makers in the loop, [51] identify two types of cooperation between decision makers and decision support systems: horizontal and vertical. In the horizontal cooperation, decision makers and DSS dynamically share the tasks to be performed. In such architecture, traffic data provided by AVLS and APC are only analyzed by the DSS that generates the best decision. This kind of cooperation is used in autonomous systems in which the only task of decision makers consists in supervising the decision making process. However,

in a vertical cooperation, DSS can be considered as a guide to the support decisions. In such cooperation, decision makers assist the system. Decision makers can interact with the system in each step of the information processing or the decision making procedure.

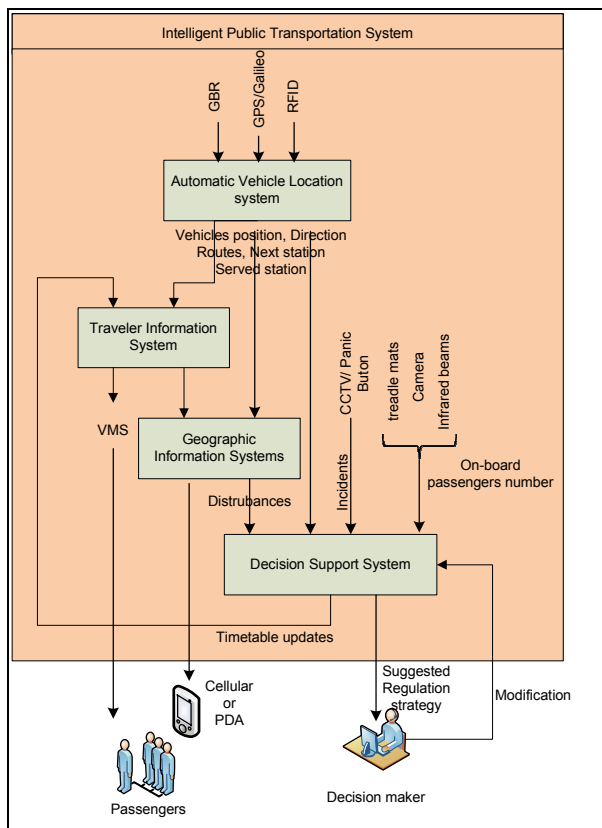


Figure 2. Information systems for IPTS

Several public transportation agencies over the world have implemented intelligent transportation systems to insure a high quality of service to passengers.

For example, [52] reported that more than 122 agencies have implemented an IPTS in USA. They reported also that Geographic Information Systems (GIS) and Decision Support Systems (DSS) were the most widely used technologies. Another example, CIVITAS [42] is an IPTS funded by the European Commission and implemented in 60 European cities, including La Rochelle, London or Frankfurt. Within CIVITAS, different components of Public Transport Information systems were implemented:

- TIS via boards and terminals, on and off the public transport system, via SMS and/or e-mail
- Internet services providing public transport information
- Over ground network map and mini map available on board public transport vehicles and other campaigns and information material to promote public transport
- Real-time traffic and parking information for drivers via Variable Message Signs

[6] developed an IPTS, named TRSS, designed according to a vertical architecture. The system integrates an AVLS (using GPS system), which provides vehicle tracking information to a multi agent decision support system. SITREPA [24] is another IPTS tested in the city of Leiria (Portugal). The system combines GPS and RFID technologies to locate vehicles on the network. It integrates a TIS to provide real time information about the network.

V. CONCLUSION

The main objective of this paper is to identify technologies on which intelligent public transportation systems (IPTS) rely to control transportation networks. We identified several technologies, such as Traveler Information Systems, Geographic Information Systems, Automatic Vehicle Location Systems and Decision Support Systems, which are all based on advanced information and communication technologies. These systems exchange different types of data, such as vehicle location, messages, alerts and videos. With respect to existing works, such as [2] and [3], our survey focused on highlighting architectural integration of data and technologies rather than presenting technical aspects of information and communication technologies.

Our literature survey shows that several directions must be explored to improve the integration of all advanced information systems. Due to the number of subsystems, the diversity and the quantity of exchanged data, IPTS must insure a high interoperability level in existing architectures. Therefore, new subsystems must be developed and integrated in architectures, which have to automatically analyze all type of data and detect events that will affect the performance of the network. Thus, they must be as generic as possible to detect any type of disturbing event. To the best of our knowledge, this direction is not well explored and no generic tools were proposed. Furthermore, such subsystems must be compatible with actual IPTS and support existing technologies without changing developed architectures.

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