Pervasive Technology and Public Transport: Opportunities Beyond Telematics

Tiago Dias Camacho, Marcus Foth, and Andry Rakotonirainy

Abstract—The advancements of technology in the field of public transport have been considerable. Information Technology (IT) has made the dissemination of information effortless, contributing to reduced perceived waiting time, increased sense of security, and value for money. Nevertheless, and in light of the ever more obvious widespread presence of powerful mobile devices, it seems that the use of technology may be geared towards supplementary services other than telematics. Looking at it from a passenger’s perspective, this article provides an overview of what IT-based services are currently offered in public transport and what is their assessed impact. We finalise by putting forward possible directions that future services might follow, and stress out the necessity to come up with frameworks that enable for the impact assessment on service quality and customer satisfaction.

Index Terms—Information Technology; Public Transport; Intelligent Transportation Systems; Advanced Public Transportation Systems

INTRODUCTION

The hazardous side-effects that road transportation has on greenhouse emission levels are well documented. An attempt to mitigate these harmful by-products of the exponential growth of personal vehicles has been to increase public transport patronage or ridership. While traditionally most improvements in public transport have been concerned with the implementation of specific transportation planning strategies, the escalating relevance of IT has been under the focus of attention. Despite some initial doubts that services such as real-time information and electronic ticketing mechanisms had on ridership levels, evidence has since accumulated to corroborate that indeed the introduction of IT-based services are advantageous, not only in establishing a modernised image of public transport but also on ridership [30, 28, 23].

More contemporary innovations have occurred in the context of public transport. The introduction of Wi-Fi connectivity inside trains and buses [12, 9], as well as the use of social media strategies [29], all represent measures to try and keep up with existing technological trends that shape our societies in this age of information [1]. Adding to this, more recent applications have taken advantage of this proliferation of IT in order to offer services which are passenger-centric; they aim at not resolving any operational issue within public transport, but instead focus on improving passengers’ journeys. Still, where

to focus in creating attractive services that come to satisfy the evolving needs that stem from the pervasiveness of smart phones, social media, and Web 2.0 technologies is not well understood. Adding to this, a major point of interest should be to try and come up with ways to determine the effectiveness that these services might have on affecting perceptions and ridership.

This article presents an overview of the most prominent IT-based services offered in public transport. It does so from the perspective of the passengers, and it starts by first describing what kind of services are currently offered. The discussion is then shifted towards how these IT-based services have managed to reshape existing perceptions of public transport, and how the recent wave of more passenger-centric services may further contribute in the modernisation and overall improvement of public transport systems. In conclusion, we aim put forward some directions to specific challenges that remain unsolved, specifically the potential paths which the deployment of these future passenger-centric services might take, and the importance of establishing frameworks to assess the impact of these service on service quality and customer satisfaction.

IT AND PUBLIC TRANSPORT

The extensive area of intelligent transportation systems (ITS) has been responsible for establishing a major technological revolution in transportation. The purpose of ITS is to improve all means of transportation by efficiently and effectively applying technology for interconnecting vehicles, infrastructures and people. The division of ITS can be summarised through the following functional fields [27, pp. 8-9]:

- Advanced traffic management systems
- Advanced traveler information systems
- Advanced vehicle control systems
- Commercial vehicle operation
- Advanced public transportation systems
- Advanced rural transportation systems

In this defining framework, the field of advanced public transportation systems - or APTS - is of particular interest to public transport. It works to provide services that facilitate the management of public transport and the dissemination of related information to decision makers and passengers alike. The reach of APTS is considerable and encompasses several areas. For this reason, many of its applications include other

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of the aforementioned areas and related technologies. Most notably, and concentrating exclusively on passengers, several services and applications within APTS relate to the offering of services specific to travellers and aiding in their journeys and in the management, collection, and payment of fares using automated mechanisms.

**Travellers’ Systems**

During recent years we have witnessed a considerable improvement in the quantity - and quality - of services offered by transit agencies. In modern public transport systems worldwide vehicles such as buses are now commonly equipped with positioning sensors which, with the aid of sensor fusion, data processing, and statistical inference techniques, work to provide accurate estimations. Most of the evolution witnessed in passenger services in public transport can be associated with improvements made in advanced traveller information systems (ATIS). Despite having several other functions outside the realm of public transport - notably in aiding private vehicle owners in their journeys -, ATIS have played a pivotal role in modernising today’s public transport systems. The purpose of ATIS is to acquire and disseminate information of interest to public transport passengers; such information includes schedules, routes, fares, and overall trip plans. Particularly, the information provided by these systems may be included within two main groups: pre-trip and on-board [35]. Nowadays both of these kind of information are disseminated in real-time, allowing for better informed passengers and facilitating decision-making.

**Pre-trip Information:** The most notable example of ATIS in the context of public transport relates to real-time pre-trip information. These so called real-time passenger information (RTPI) systems have become an element of modern public transport systems throughout the world. Real-time information dissemination has been present throughout many years in modes such as metro systems, but only in recent years has it started to become pervasive in other modes, such as buses and light rail. In the present day, this is seen by the ubiquity of “at-stop” electronic displays installed at public transport stations and centrals [8].

The relevance that real-time information provision has acquired is exemplified by the necessity to specify working protocols for information exchange between public transport stakeholders. The service interface for real-time information specification along with Google’s transit feed specification [14] are examples of such protocols, which have been established as standards for several transit agencies worldwide. Transit agencies in several cities, including major metropolises such as London and New York, have become aware of the potential of making their data open to third-parties and now offer both static and dynamic versions of their datasets. This in turn has led to the development of applications that continuously foster the capabilities of IT and modern day devices, such as smart-phones and tablets, therefore extending the provision of real-time information provision beyond the boundaries of fixed locations.

OneBusAway (see Fig. 1) is an example of such a service, where passengers making use of their mobile devices acquire position of buses and estimation of arrival at specific stations [11]. The system recognises the difficulties of deploying real-time information systems throughout all bus and rail stations, and as such sees mobile devices as a natural solution to ensure that passengers acquire reliable and up to date transit information. Similar applications to OneBusAway include the BusTime application for the city of New York, or the more general NextBus infrastructure.

Recent efforts on this particular field have additionally leveraged the possibilities created by geopositioning and the use of the “wisdom of the crowds”. The Tiramisu crowdsourcing application demonstrates how it is possible - and indeed feasible and accurate - to implement an application which uses the transit operator’s historical data along with content contributed by the passengers themselves to provide valuable information about estimated time of arrivals and crowding levels of buses [34]. In essence, the application utilises the ability of the passengers to act as sensors to overcome the lack of automated vehicle location systems to provide for reliable real-time information.

The provision of pre-trip information may be provided for more than a single-mode - or what some would refer to as unimodal information provision. More recent journey planners exemplify well such a kind of application. The need for passengers to know where to board vehicles and which transfers to take, allied with the evolution of Web technology, have laid the foundations for increased interest on multimodal journey planners [22]. Increasingly, transit agencies deploy on-line systems to aid passengers in knowing where, when and how to board a public transport vehicle. Furthermore, these systems estimate the length of journeys and establish which provisions should passengers take (including walking directions) in case of journeys that span over multiple modes.
of transportation. Google Transit perhaps represents the most relevant application that is not bound to any particular transit agency, although it is usually for transit agencies to provide their own implementations.

**On-Board Information:** Another noteworthy real-time dissemination information service that has been taking prominence in vehicles such as buses is on-board information. It is recognised that one of the detrimental aspects for casual passengers to make use of public transport is the lack of information while travelling, as this affects considerably the decision-making process [20]. While rail systems have for years offered means for passengers to recognise current and upcoming stops (using commonly a combination of visual and audio media), this is not often the case with buses where it is up to the passengers to recognise their surroundings in an attempt to correctly identify where to alight the vehicle.

It has therefore become of interest to transit agencies to try and augment their trips with systems that allow for a real-time dissemination of content to passengers. PATH2Go demonstrates an example of an integrated infrastructure which offers the ability to produce real-time estimations to their passengers [32]. While many agencies offer this service making use of dedicated electronic equipment on-board (e.g., screens), the PATH2Go infrastructure takes this kind of service to the next level by facilitating the acquisition of the information using mobile devices and promoting personalisation of content. An example interface of the PATH2Go mobile application is seen in Fig. 2.

### Fare Collection and Management

The range of ITS on public transport and its influence on passengers reaches beyond information dissemination. Other fields of particular interest have stem from the field of ITS that came to reshape how public transport is seen. The use of IT and electronics to automate the collection and management of fares has been another considerable advancement. These automated fare collection (AFC) systems exemplify the concrete application of technology in the context of public transport and how it came to immensely facilitate procedures which not many years ago where manual, error prone, and time consuming.

Paper tickets have historically been the standard when it comes to revenue collection, but they were replaced to a certain extent in some modes by magnetic cards. The limitations of both of these technologies for fare collection and management soon became apparent and the recent deployment of smart-card technology in order to produce a technological advanced and feasible system for fare collection is rapidly becoming the norm in public transport. A well known example of a smart-card is London’s Oyster card which allows passengers an unified means for boarding many of London’s public transport vehicles.

The use of smart-cards have a noticeable effect from the passengers’ point of view, as it is known to improve commodity and convenience [23]. Passengers do not have to worry about buying tickets or losing time while boarding vehicles such as buses. Furthermore, the rapid adoption of near field communication technology by mobile device manufactures is promising to advance the field of AFC to new levels, as the need to make use of separate cards for fare collection and management is lost, with passengers having the possibility of using their own mobile devices for this purpose.

### Towards Passenger-Centric Services

Technology has influenced the appearance of other services which are not under the grasp of the field defined by ITS. In essence, these are services which have been made possible by the notable technological advancements, and the role that IT has gained within modern societies. Although these services did not spawn directly from the area of ITS - and more concretely from APTS -, it can be stated that they share common objectives to APTS in the sense that they were thought of as a mean to produce a better overall public transport service.

One of the main issues with public transport has been to solve the problems which impaired people struggle when commuting or travelling. Clearly, it is not easy to use a public transport system if a passenger suffers from some kind of mental or physical impairment. The evolution of mobile devices and their ability to be seen as effective sensors has led to the development of several types of services which have come to aid in producing better accessibility to public transport for impaired passengers [6].

The ability of using mobile devices - and even the passengers themselves in a similar fashion to crowd-sourcing -不及传感器也已经由塞浦路斯利用了开发的See Say应用，同与马萨诸塞湾交通管理局[21]。The objective is to provide passengers with the ability to contribute with content (e.g., images, text) about any kind of suspicious activity, allowing for direct communication with the transit police. Additionally,
several contests have been promoted worldwide by transit agencies, enticing developers to produce applications that make use of given datasets. The App Quest challenge demonstrates the possibilities that develop from these contests, with applications such as OnBoard and Art by Subway delivering innovative services to passengers. The former allows for a real-time exploration of outside locations while travelling on a bus, while the latter enables passengers to explore artwork associated with the metro system. The Canopy system designed to allow for passengers to access information about the outside environment of a metro system using a screen installed on the ceiling of the metro vehicles demonstrates another service aimed at producing a “window of escape” from the involving environment [2]. It is pertinent to note that these applications do not come to solve any concrete operational or logistic issue with the public transport infrastructure in itself, but instead come to supply passengers with means to engage in more fulfilling activities while they travel.

Another technological innovation in public transport has been the introduction of Wi-Fi connectivity. The deployment of this technology has started to become regular, with transit agencies rolling out Wi-Fi connectivity in both infrastructures (e.g., railway stations, bus centrals) and vehicles, including light rail and buses. For some companies, such as the low-cost “Curbside” buses, free provision of Wi-Fi has become a standout element of the provided service.

Even more contemporary has been the adoption of social media by transit agencies. The proliferation of social media has become evident, with the total number of users expected to reach the billion figure in a near future. Transit agencies have realised the usefulness of social media as a mechanism to reach out to passengers. As such, they have engaged in committed efforts to develop strategies and services that leverage this kind of technology. Several agencies now offer Twitter, Facebook, and YouTube channels, raising the promise for better timely updates of possible disruptions or changes in the service, more efficient information dissemination of fare updates or service modifications, and increased passenger engagement by enabling two-way communication channels [29]. Perhaps a more applied application that stemmed from the proliferation of social media is seen by the IHeartM15 effort, aimed at promoting social networking within a specific bus route in New York. This is nevertheless an effort started by commuters themselves, and which has not received support by the transit agency.

It is curious to see the evolution of IT-based services and how these came to reshape the modern day image of public transport. Undeniably, IT and its application in public transport - either under the perspective of ITS or other alternative and more passenger-centric services - have produced major advancements and improvements. Real-time information, smart-cards, and applications for exploring the outside environment are all examples how IT has been utilised as a means to produce a better service overall. Nevertheless, it is still pertinent to ask to which extent has this objective been accomplished?

**What Impacts Public Transport Use**

Traditionally, most improvements in public transport have been confined to the implementation of specific transit planning strategies. These strategies in turn emphasise certain factors of public transport use which have been identified by the literature as being elemental in establishing service standards. We refer to these as being traditional factors of influence. Factors such as service frequency, on-time performance, and information availability are among the most influential in establishing service quality and customer satisfaction. Service quality refers to judgment of the passengers in relation to the service being offered, and it is known to influence directly customer satisfaction levels. It was only recently that ITS-based services have started to been assessed in public transport for their impact on the overall service quality.

The case for real-time information systems seems to be clear, as some researchers identified this kind of information provision as essential from the passengers’ point of view, and even further classify RTPI systems as necessary components for most European transit agencies Politis et al. [24]. Daslakis and Stathopoulos [7] further refer to RTPI systems as a fundamental building block of public transport service quality and customer satisfaction levels. They point out that transit agencies should focus on making this information as accurate as possible, as the lack of quality might have negative impact on ridership levels. A longitudinal case-study of the Bus Tracker system in Chicago has further corroborated the effect that these systems have established on passengers and their influence on ridership [28]. Additional studies have indicated the potential effect that ATIS might have on attracting potential new passengers if real-time information is consistently offered at free of charge [35]. Additionally, ATIS services that use the passengers’ own mobile devices seem to indicate a similar effect as other types, with the appraisal of the OneBusAway application indicating positive effects on perceived waiting time [30].

The use of AFC systems and particularly smart-cards has also come to change existing perceptions of passengers towards public transport, and further sparked a series of potential applications that extend beyond its original purpose of revenue collection. Passengers find smart-card-based AFC systems advantageous, as they provide for better payment and management experience overall [23]. Smart-cards provide additional convenience to passengers, as they are small, endure for many years, and allow for payment/recharge of fares in a decentralised manner. They further contribute to smoother journeys, as their use reduces the time that is wasted collecting fares when board transit vehicles. They are also known to contribute to increased reliability of the service, a concept that is directly connected with that of service quality. Other applications may be built around the abilities of smart-cards. As noted by Ceapa et al. [5], the analysis of smart-card data may leverage new services that foster not only integration between the systems that compose ITS - which by itself is a vivid research issue -, but also be a useful tool in achieving the concept of personalisation up to the individual granularity.

The offering of Wi-Fi connectivity seems to be the best
studied type of passenger-centric service in public transport. Preston and Wall [25] have studied how provision of Wi-Fi inside trains gains wide acceptance by passengers. Still, while initially the study had indicated a willingness to pay for accessing the service, more recent studies reveal that the proliferation of Wi-Fi has become quite regular within most urban environments, and that such has led passengers to increasingly anticipate the free provision of the service by transit agencies [9]. Despite the increase of mobile devices with 3G and 4G connectivity, having free Wi-Fi inside public transport vehicles seems to be a considering factor in using public transport altogether [12]. Arguably, service provisions such as Wi-Fi accessibility seem to indicate that these are slowly building up to be an intrinsic part of the modern public transport system, and their influence on service quality seems to be becoming apparent.

It could be argued that social media strategies have been set in motion so that again a modernised image of public transport is conveyed. Despite this mostly being the case, research assessing the impact on passengers is lacking even though data indicates that social media implementation is advantageous for the transit agencies themselves [29]. It is still only fair to assume that many of the aspects considered advantageous to the agencies (e.g., timely updates, passenger engagement, entertainment) have a reciprocal effect on the passengers.

The case for most modern types of applications seems blurry though. Services and applications such as See Say, Canopy, IHeartM15, and many others may well be assessed from their design or user perspective, but their effects on service quality and ridership are not well understood. While these services and applications share in essence the same purpose of providing a better service overall, they differ essentially in the way they go about to achieve that purpose. While most ITS-based services have indeed been designed with an operational mindset, aiming in essence to facilitate journey planning and producing more accurate information, the recent appearance of alternative services such as Wi-Fi, social media and a myriad of applications which are based on existing and emergent IT trends, have the passengers as their main focus of attention.

**IT, Locality, People and Opportunities**

Although much has been achieved throughout the years due to the vast evolution of ITS-based services, it has not been until recently that the development of services and applications has started to be centred towards what several researchers consider to be the most important element of public transport: the passengers. ITS-based services have stemmed from existing operational concerns and their purpose - from a passenger’s point of view - is to facilitate journey planning, fare payment and management, and to better inform passengers and aid them on their decision-making. On the other hand, services as Wi-Fi connectivity, social media tools, and several other recent services and mobile applications have come to evolve beyond existing taxonomies of ITS, and have instead started centre around the passengers themselves.

This idea of gearing technology within public transport towards a more passenger centric provision is something that gains prominence given the societal relevance that IT and mobile devices obtain [1], and one that follows closely Weiser’s founding ideas of ubiquitous computing. The proliferation of mobile devices, such as smartphones and tablets, seems undeniable and one that is already changing the activities in which passengers engage while travelling [26]. The relevance of IT in younger generations seems also to be relevant, with researchers indicating that urban citizens are starting to become more preoccupied with their ability to have access to the Internet and maintaining their social networks than owning and driving private vehicles [19]. It is also pertinent to note that as technology becomes part of our daily lives, so does our perceived mastering of these technologies [18]. In a way this signifies new opportunities for the deployment of IT-based services that foster existing established technologies, such as social media and crowd-sourcing, as passengers are becoming proficient in their use.

The notion of ubiquity is also intrinsically connected with that of locality. Hornecker et al. [15] refer to the opportunities which appear not due to the existence of any particular issues or problems that require solving, but due to the peculiarities that certain spaces potentiate. Such is the case while travelling in public transport vehicles, where the space - and arguably also time - unlocks particularly exciting possibilities for engagement through the use of IT. As an example, Foth and Schroeter [13] talk about the “whole journey” concept, in which they identify three distinct phases - before, during, and after the journey - that define a public transport trip. The application of location-based services to produce additional engagement with passengers seems therefore a clear opportunity which has already seen development, both for ITS-based and passenger-centric services. Still, the opportunities that arise from location-based services are wide and far reaching; being able to meet the emerging needs of the passengers by means of these services is where the difficulties lie though. Still, it seems that exploring concepts such as social-media and crowd-sourcing bring about clear advantages from several different perspectives.

One is the further narrowing of location-based services to relate directly to social networks and therefore to people. The term location-based social networks is a notion which bridges the elements of locality and people, additionally leveraging the use of IT for this purpose. Even though one might see examples of social networks being set up to accommodate for particular subjects - one of them being public transport -, the concept of location-based social networks in the context of public transport has only been explored at the surface [3]. We can argue that the definition of location-based social networks matches well with the idiosyncrasies that define public transport vehicles altogether [33]. Passengers share a space that continuously moves through a set of locations during a journey; still, the interdependency of the location dimension between passengers is maintained and may be further explored as a means to promote not only the actual consumption of information, but also to potentiate participatory behaviour and further nurture the concept of “produsers” [16, 4].

The sense of community may not necessarily be confined to the notion of social networks, but instead be extended
to include services that captivate those included within the sociotechnical systems which so well characterise public transport vehicles. The relevance of information consumption, the tailoring of that information according to location of interest, and the possibility to promote discussion between interested parties are all elements which the advent of Web 2.0 has made possible. As these technologies have become prolific, the use of media type which people use to satisfy their informational and societal needs have naturally shifted [18]. As such, the future of services such as the offering of free newspapers at metro and rail systems seems most likely to be mediated and augmented by the use of IT. This represents an example of how the use of mobile and location-aware technologies may be put into practice to foster an already existing service and enhance it with the ability for personalisation of content, interactivity, and content contribution, all of which would be difficult to achieve through the use of static, legacy media.

The array of opportunities that arise from exploring the literature and what has been achieved through the deployment of recent applications are immense. Most ITS-based services are concentrated in solving specific issues of public transport operation and make public transport journeys more bearable. Recent services though have taken on a different perspective and are more passenger-centric. In a way, these services may be stated to already moving towards the notion of data driven ITS [31] or that of “ITS 3.0” [10]. What we are witnessing is a redefinition of the way services and applications are being designed and developed in the context of public transport. Still several challenges remain to be answered.

Challenges and Conclusive Remarks

Perhaps the main issue that transit agencies face today is to come up with ways to produce an attractive service to their passengers. This is a task that requires constant effort, weighting and prioritisation of which factors to concentrate on. Offering flawless real-time information to passengers would have little impact if the frequency of the service is too low. The same could be said in relation to social media platforms; offering a sophisticated means to engage with passengers through social media would be of little interest if the public transport service itself is not reliable [29]. It seems clear that transit agencies still require to concentrate their efforts on more traditional factors and ITS provision, as these are already known to produce significant impact on ridership [17, 30, 28], but they should also be aware of the possible impacts that future services might play in establishing the way we all look at public transport.

This article has reviewed the IT-based services and applications that currently are offered to public transport passengers. The shift from ITS to more passenger-centric services seems to indicate that researchers and developers are starting to look at the introduction of services from the user experience perspective. As such, two pertinent questions may be formed: 1) What direction(s) should the future wave of these passenger-centric services and applications follow?; and 2) What kind of assessment framework should be used in determining the impact of these services in service quality, customer satisfaction, and ultimately in the use and recommendation of public transport?

For the first question, it seems that the future is not only composed by the privatisation of the public space by means of IT (e.g., personalisation of disseminated content), but also by the promotion of an actual participatory culture in order to facilitate information consumption, content contribution, and also to solve specific issues that hinder the experience of public transport passengers in general. An interactive news platform that disseminates content that is exclusive to the locations where a transit vehicle travels is an example of an application that foster IT for information consumption and content contribution. This kind of service is interesting not only because it uses digital media and its interactivity to satisfy constantly evolving informational needs [18], but also because it tries to satisfy social (e.g., community) and communicational needs through the use of interaction with fellow passengers.

For using these services to solve specific problems that already exist in public transport, an example would be a service that fosters communication between passengers to signal for the availability within a crowded train. With crowding being an issue within public transport, finding a seat - especially in medium/long journeys - can hinder the journey experience considerably. Therefore the use of mobile devices to signal the availability of a seat within the co-located space of the train would aid in lessening issues related with crowding in public transport.

As for the second question, should we follow a methodology which includes technical, operational, user acceptance, economic, and organisational evaluations, therefore pursuing an approach similar to that used for ITS-based services [24]? Or should we simply try and determine how may these services affect behaviours and intentions to use public transport through established psychological-driven frameworks [17]? While the latter seems like a valid option altogether, assessing the impact of these passenger-centric services will most likely require multiple perspectives, with evaluations on technical issues, user acceptance levels, and organisational impact being pertinent. Despite systems such as Canopy requiring possibly economical evaluations due to their potential high costs, mobile applications will make use of the passengers’ own devices - and possibly already existing infrastructures, such as Wi-Fi - therefore reducing costs considerably.

In sum, the field of public transport is likely to be flooded with a series of applications in the near future that aim at producing not more efficient or better planned journeys, but instead more enjoyable journeys - journeys which passengers look forward to. While it is relevant to come up with paths in which these hypothetical services and applications should follow, it is also essential to determine how should we assess the impact of these services in elemental aspects, such as service quality and customer satisfaction. Ultimately, being able to determine this is what is going to drive transit agencies in the adoption of these services.

Acknowledgements

The authors are grateful to the CRC for Rail Innovation (established and supported under the Australian Government’s
Cooperative Research Centres program) for the funding of this research.

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