Towards Smart and Sustainable Multimodal Public Transports Based on a Participatory Ecosystem

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Nic Volanschi
INRIA Bordeaux - Sud-Ouest
33405 Talence, France
Email: eugene.volanschi@inria.fr

***Abstract*—Leveraging on the recent availability of open data about public transports, the last generation of smartphone applications provide highly personalised guidance to passengers during their trips. This smart assistance definitely improves the passenger comfort and streamlines their trips, especially in case of infrastructure incidents and/or multimodal trips.**

However, there are important limitations stemming from the unidirectional flow of information going from transport operators to passengers: (1) waste of computing resources, partially defeating the purpose of sustainability, and (2) missed opportunities of optimisations by the transport operators, which do not exploit detailed real-time passengers information. This paper presents ongoing work towards smarter and more sustainable multimodal transports based on a full-duplex ecosystem in which passengers and transport operators actively exchange information and react correspondingly. As first steps in this direction, we show how this integration can lead to greener computing applications by varying the balance between the smartphone and the cloud, and present a few concrete optimisations enabled in this model, during the trip itself or on a longer term by improving the transport infrastructure. We illustrate this ecosystem with a smartphone/cloud application prototype, and elaborate the remaining challenges for fully implementing this vision, including issues like interoperability, scalability, and acceptability.

***Index Terms*—public transports, assistive applications, participation, sustainability, bicycle-sharing systems**

I. Introduction

With the expected increase of the population percentage living in urban areas, from 50% (as of 2009) to 70% (forecast by the United Nations in 2050) [13] and the environmental crisis, there is a growing need for sustainable management of city infrastructures such as public roads, and for reducing gas emissions. Public transportations are an important part of the solution to these sustainability issues by reducing private car road occupancy and air pollution.

Computing technology has helped passengers since decades for using public transportation systems more easily and in a more predictive way. Traditionally, transport operators (either public or private) have offered to passengers both static transportation timetables and online journey planners based on this static data or on its real-time counterpart.

In the last decade, three new factors radically changed the assistive transport applications landscape:

- the massive adoption of mobile computing, based on standard and open smartphone platforms such as iOS and Android, brought the possibility of mobile usage scenarios;
- the trend for providing open data, in particular on public transports, including both static and real-time data, enabled crossing data from different data sources and web services;
- the massive adoption of bicycle-sharing systems, covering 712 cities on five continents as of 2014 [15], introduced a new transportation mode, relatively resource-constrained and highly dynamic, thus very different from the other modes, but meant to be integrated with them.

Due to these factors, the journey planners first became available on mobile smartphones, and both desktop and mobile versions of journey planners began multimodal by crossing data from different sources. For instance, trips may be computed which aggregate transports modes such as buses, metro, tramways, and public bicycles, check the presence of incidents on the corresponding modes, and check availability of bikes at the corresponding stations.

On the other hand, the mobile version of assistive applications for public transports began to exploit the mobility context, such as the current passenger position, to continuously guide them during their trip by providing highly contextual and highly personalised information. For instance, incidents arriving during a trip (and no more only before departure) may be reported just in time and only to the concerned users.

Mobile assistive applications for passengers definitely may increase the usability of the public transport infrastructure of a smart city (modulo the usability of the application itself). However, two important issues remain to be solved to obtain a smarter and sustainable transport system.

Firstly, from the sustainability perspective, the useful contextual passenger information comes with a high energy cost. Indeed, to be informed about possible incidents on their next modes, many users in the same transport vehicle must keep their applications on in GPS mode, and must do so every day even for a well-known trip such as commuting from home to work and back. This proliferation of battery-consuming applications clearly defeats to some extent the sustainability purpose of public transportations in the first place.

Secondly, these mobile applications follow a consumer-only model in terms of open data. As a consequence, transport operators cannot take advantage of information that is available within each user's application, such as their destination and planned trip, that could be useful to optimise the infrastructure. In particular, the anticipated needs for the relatively scarce public bicycle resources cannot be used for preventing resource shortage. This limitation holds both on the short term, when bicycles could be made available to a needed slot, and on the long term, as bicycle misses get unnoticed by the operator.

To solve these issues, and following the trend towards participatory assistive applications in other domains (see Section VI), this paper advocates for a participatory assistive application model in multimodal public transports, in which useful information also flows from the user to the transport operators, in exchange of more contextualised information, less battery consumption, and hopefully a better transport service. This data flow complements the open data flow consumed by the assistive application thus creating a full-duplex information ecosystem, and may lead to a more sustainable and mode efficient transportation system. As some first steps in this direction, we investigate some concrete benefits of this model in terms of energy saving and possible transport optimisations, and describe a proof-of-concept application that already implements part of this model. The challenges remaining for fully implementing this vision are further discussed. These challenges include interoperability, scalability, acceptability, and experimental or simulation-based validation.

The contributions of this paper can be summarised as follows:

- We identify useful information that can be generated automatically during the ordinary use of a mobile assistive application in public transports, so that it may serve also as a data source, not just as a (open) data sink; such information includes for example the passengers' final destination, their real ongoing trip, but also their ideal trip, if for some reason they are different.
- We show how this information, currently unused by transport operators, could be leveraged to build a participatory transport ecosystem so as to concretely optimise several of its aspects: (1) sustainability, by decreasing battery consumption of the assistive applications, and (2) performance of the transport service, by avoiding resource shortage, both on the short term during the passenger trip when possible, and on the long term by providing missing inputs to the process of re-dimensioning the resource pools.
- We present our current prototype of assistive application that partially implements this ecosystem, and discuss the remaining challenges for implementing and validating the full vision described.

The rest of this paper is structured as follows. Section II describes in more detail the consumer-only model followed by state-of-the-art assistive applications for multimodal transport. Section III shows how a participatory model can naturally extend such an assistive application and some concrete optimisations that are enabled by this model. Section IV discusses a first prototype of this approach. Section V describes the remaining challenges of fully implementing this vision. Section VI describes related work, and Section VII concludes.

II. Consumer-only assistive applications

This section describes using a concrete scenario how the latest generation of assistive applications in public transports (*e.g.*, [5], [14]) are able to exploit open data to provide highly contextual and highly personalised information and guidance to passengers, resulting in an increased QoE (Quality of Experience) of the transport service, and a more streamlined trip in case of infrastructure incidents.

In cities where the public transport open data is most widely available, it includes information such as: static maps and timetables complemented with the real-time position of the corresponding vehicles and the expected real-time arrivals at each stop. This information ideally covers all the different public transportation modes serving the city, such as railway modes (tramways, metros, local trains, ...), buses, boat shuttles. Additionally, transport operators or city authorities also provide information about current events or incidents affecting the transport infrastructure, such as accidental or scheduled line disruptions. The more recently available bicycle-sharing systems (BSS) are also covered in such cities by open data providing static maps of the bicycle stations and their capacity (number of slots), complemented by real-time data including the status of each station (normal functioning or under maintenance) and the stocks of available bicycles and free slots at each station.

Based on such set of open data, online and mobile journey planners are able to compute accurate multimodal trips, taking into account the eventual current infrastructure incidents and delays, and the availability of scarce resources such as BSS. In the particular case of a mobile assistive application, a typical scenario involves computing a journey starting from the current position (as provided by the smartphone's GPS sensor) to a specified final destination point, and activating the "on trip" mode upon departure. In this mode, the passenger is guided step by step through their journey, taking into account their evolving position and recomputing the trip on any missed step in the schedule. By continuously comparing the GPS position with the scheduled vehicle real-time position (when available), the application may infer when the users steps in or out a vehicle. The application may thus send notifications to the passengers such as to prepare stepping down at the next station, but also to inform them about emerging incidents in the infrastructure. Ideally, the incident notifications are only sent when they directly impact the remaining trip and require recomputing the journey.

Although we are unaware about such a feature in current assistive applications, it is possible in principle to also send "positive" notifications to the passenger when a pending incident or resource shortage has been resolved, and propose a better trip if available — possibly the ideal trip that has been ruled out initially because of the incident or shortage, if this ideal trip is still applicable at the current point.

Note that the starting and ending trip positions are not sufficient for deducing the ideal trip because a journey planner typically applies a multi-objective optimisation search with no unique best trip: it typically returns a set of trips from which the passenger chooses their best one according to their own preferences (for instance, implying the least number of transfers, arriving the earlier, etc.). In case of platform incidents, journey planners typically also show unfeasible trips; only when selected, these trips are marked as unfeasible, suggesting alternatives. Ideal trips involving BSS resource shortage are not even considered unfeasible *a priori*, because a shortage at departure time does not necessarily mean that it will still hold when the BSS station is actually reached. Thus, the ideal trip for a passenger can be recorded without extra effort from their part — it is the one for which one of the alternative suggestions has been selected for execution.

As may be seen in the above scenario, various kinds of information about the user are managed by the assistive application to provide highly personalised, context-dependent notifications:

- the departure and final destination points are used to only notify about incidents impacting the current trip;
- the evolving current position is used to infer missed steps in the schedule and recompute the trip if necessary;
- the ideal trip that could not be considered initially might be used to send positive notifications about resolved incidents or shortages.

Thus, all this user information is only consumed by the assistive application, crossed with open data provided by transport operators and city authorities. The current assistive applications are therefore user data and open data consumers.

Summarising, assistive application following the consumer model are able to increase passenger's awareness about infrastructure constraints and guide them to *cope with* these constraints, by minimising their impact on the trip. However, as the next section shows, these same kinds of user information consumed by the assistive application could be also useful as a data source for the transport operators to *act on* the infrastructure and their operation, possibly eliminating some shortage constraints or suggesting re-dimensioning of resource pools. On the other hand, producing user data to the transporter can also help to factorise some redundant assistive computations in the cloud, saving battery consumption on many passengers' smartphones.

III. A Participatory Assistive Application

As can be seen in Figure 1, a participatory transport ecosystem is obtained by turning a consumer-only assistive application in a consumer of open data and producer of user data. User data includes the kinds of information discussed in the previous section, namely the ongoing trip with its schedule, final destination, and current position, and eventually the ideal trip that was not feasible when the journey was planned. Together with this data, a user identifier is also be communicated to the transport operator. This is represented with a separated dotted line, because this data was not needed in the consumer-only model, where the user data were consumed locally by the private assistive application. This user identifier will allow the transport operator to provide personal

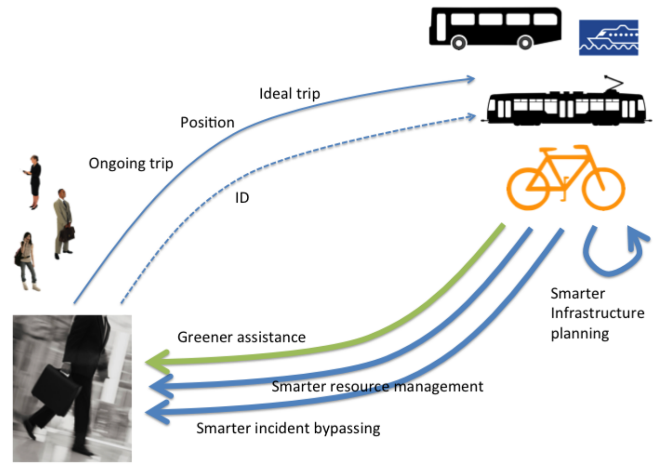

Fig. 1. Collaboration diagram in a participatory assistive application for public transports.

guidance and assistance during the passenger's trip. The kind of user identifier varies from an anonymous trip identifier to a nominative identifier such as a cellphone number; this depends on the intended optimisation. By providing these data, the passenger enables several optimisations (represented by bolder lines in the diagram), some of which directly concern them during their trip: greener assistance, smarter incident bypassing, and smarter resource management. The fourth optimisation, smarter infrastructure planning, directly concerns the transport operator.

The following subsections detail these different optimisations and shows how they can be performed.

A. Greener Assistance

Depending on the kind of user identifier passed to the transport operator, various balances of the assistive computations between the smartphone and the cloud are possible. For the least, the smartphone GPS can be turned off; for the best, the passenger smartphone data connection can be switched off, or even it can be replaced by a lower-tech cellphone. Thus, different kinds of user identifiers, ranging from an anonymous ticket number to their cellphone number, enable different privacy/sustainability tradeoffs.

In all scenarios, part of the assistance is performed in the transport operator's cloud application, which keeps a track of all ongoing trips. Based on this followup, the transporter may provide personal guidance to the passenger along their trip, including in case of incidents, shortages, or resolution thereof.

a) Turning the GPS off: In this scenario, the user identifier (or shortly, ID) is the ticket or transport card number used by the passenger. In case of a card number (typically, a monthly or annual subscription), the pass number can be entered in the assistive application only once, at subscription time. In case of an anonymous ticket, its number must be scanned by the assistive application (using optical character recognition for instance) at the beginning of each trip.

Using this ID, the operator may follow an anonymous user during their trip by relying on its current ticket validation infrastructure. Indeed, transport operators usually require every passenger to (re-)validate their travel ticket or pass at the beginning of the trip and at every transfer. This currently allows transport operators to record a multi-hop and possibly multimodal trip *a posteriori*, without knowing where the passenger is heading to. In contrast, when using the user data and ID provided by the assistive application, the transporter may follow passengers in real time along their planned trips and provide them proactive personal guidance. Any missed step in the schedule, or deviation from the planned trip may be detected; the real-time position of vehicles may be used to notify passengers for stepping down at the next station; in particular, delays in public transport vehicles are also known to the transporter, etc. As a consequence, the smartphone GPS can be turned off, saving battery consumption. When multiplied with a great number of passenger equipped with assistive applications, especially for frequent commuters, the energy savings may become very significant.

Note that while performing trip segments that do not involve a transport operating on a pre-established line, such as while walking or using a BSS, the GPS might be turned back on, if guidance is needed. On the other hand, it might be useful to turn the GPS on upon request from the cloud, if the operators' sensing infrastructure cannot distinguish between two transport lines that share the same ticket validation gates, such as two metro lines departing from a same station in different directions.

b) Travelling offline: If the cellphone number is communicated as the user ID instead of the ticket number, the transporter may guide the passenger during their trip as in the previous scenario, but notifications may be sent by SMS rather than using a data connection opened between the assistive application and the cloud. In practice, using SMS will perhaps require reducing the number of notifications by only keeping the most important ones, typically incident detection and the associated alternative trip solutions. The cellphone number could be communicated to the transport operator at the beginning of each trip, or be permanently associated to a nominative travel pass number, when such a pass is used.

This scenario offers less privacy guarantees, but is applicable to reduce data costs (in addition to turning off the GPS), and in particular to passengers with no mobile data connection subscription at all.

c) Using a lower-tech cellphone: At the extreme, passengers owning a lower-tech cellphone not supporting installable applications may also be guided by communicating their cellphone number as the user ID when using an online journey planner at home (on a tablet or computer) before departure. The cellphone number can be asked as a last optional step in the journey planning process, and may result in the selected trip to be sent by SMS, as well as any eventual subsequent assistance. This scenario may apply to many users not owning a smartphone (among which may elders), or not wishing to install applications on their smartphone. In this case, there is no mobile assistive application at all, but the participatory ecosystem is initiated by the journey planner used at home.

In all the scenarios above, the assistive application is greener, as it consumes less power by saving GPS sensing, by using a smartphone as an ordinary phone, or by requiring only a lower-tech cellphone, typically much less consuming.

B. Smarter Resource Management

When passenger ongoing trips are communicated to the transport operator at departure time, the operator may use this information to improve the management of scarce resources such as BSS. More precisely, a multimodal trip including a pubic bicycle typically contains the bicycle mode as the first or last step, because BSS were introduced to cope with the "first/last mile" connection to other transport means. Statistically, half of such multimodal trips should therefore contain the bicycle segment as the last one. In this cases, the BSS operator may use the anticipated bicycle need signalled by the assistive application to solve shortage problems, provided that the delay is significant enough and that an effective action is available.

As far as the anticipation delay is concerned, it may be quite significant in large urban areas. For instance, in the Paris area, the average commute time using public transports is of 43 minutes [11], and 8.6% of these trips exceed one hour [16].

For a trip ending with a BSS segment, actually two needs may be anticipated: the need for an available bicycle at the pickup station, and the need of a free slot at the delivery station. The latter need comes nearer the end of the trip, which increases even more the anticipation time. Thus, it is reasonable to assume that the needs for a bicycle in a trip ending with a BSS segment may be frequently anticipated by 15 to 45 minutes in large urban areas.

As far as the possible actions for the BSS operator are concerned, there are typically two alternatives [7]:

- redistribution of bicycles across the stations is periodically carried out by using a number of dedicated trucks, and
- incentives are given to the users to leave their bicycle to a different than the originally intended station. Incentives are regulated through a pricing or reward scheme which is changing online according to the current state of the system.

The latter alternative, of dynamic incentives systems for bicycles repositioning, has already been deployed in real-world BSS ([7], p.18), and may directly benefit of the anticipated demands provided by a participatory assistive application in multimodal transports. By using such dynamic incentives, the transport ecosystem becomes really full-duplex, as passengers and transport operators exchange information and both react with adequate actions to optimise the service.

In the former alternative, consisting in manual bicycle repositioning, the benefit of providing anticipated bicycle needs is less obvious, because the number of relocating trucks is limited, and it may be unjustified to modify their current route for isolated demands. A less naive approach is to aggregate the anticipated demands for each BSS station, for all the ideal trips that could not be satisfied and are currently performed on alternative trips. When the demand for some BSS station reaches a given threshold, it can be considered by the currently operating trucks to deviate their routes.

No matter what alternative is taken to satisfy pending individual or aggregated demands, the resource shortage is not solved instantaneously. In the mean time, the cloud application must maintain for all the corresponding passengers their unsatisfied ideal trip. Whenever a shortage is solved, those passengers will be notified if their current position is still compatible with their ideal trip. Note that such positive personal notifications due to effective real-time operator reactions could considerably improve the operator's image in the passengers' esteem.

Thus, reporting the unsatisfied ideal trips by the assistive application is an essential complement to the anticipated needs themselves.

C. Smarter Infrastructure Planning

Correctly sizing pools of scarce resources such as shared bicycles or electric vehicles is an important problem in the planning of a smart city transport infrastructure. One of the crucial inputs to such planning is the vehicle availability, that is, the percentage of requests that could be served [2]. For BSS, unserved requests are caused by empty or full stations, but currently BSS systems do not record the number of unsatisfied requests. To circumvent this issue, some research works try to derive missed requests by indirect approaches, for instance based on taxi usage, weather and spatial variables as covariates to predict bicycle demand [17].

Instead of such indirect estimations, an assistive application can measure the real number of request misses, each related to an unsatisfied ideal trip. Even though not all passengers are equipped with an assistive application, it is sufficient if their proportion is big enough to generate a statistically significant (direct) estimation.

D. Smarter Incident Bypassing

In case of an infrastructure incident with significant impact, such as a high-capacity railway disruption blocking all the trains of one or several lines, a consumer-only assistive application can only increase a passenger awareness about alternative solutions. However, if the disruption lasts a non-negligible time, transport operators usually take compensating measures. For the least, announces are broadcast to the impacted passengers about their possible options. For the best, shuttle systems are set up to compensate for the disruption of a backbone, which is sized according to the number of passengers in the interrupted vehicles — which is available to the operator via its ticket validation system.

The information produced by a participatory assistive application, and in particular each passengers final destination, may serve to the transporter to personally recommend to each passenger their best option among existing or newly set up services, and also to better size the temporary shuttle service — by counting only the passengers directed to the shuttle.

IV. Proof of Concept

The participative approach described in the previous section has been partially implemented in the form of a proof-of-concept assistive application for multimodal transports called "VIP". This name was chosen both because such an application is meant to deliver an increased transport QoE and QoS, and because the information provided by every passenger is valuable for optimising the system as a whole.

The application was developed in Java by a team of 8 students during a one-semester part-time programming project. The resulting prototype was subsequently enhanced and maintained by the author. The VIP application assists passengers travelling in the urban area of Bordeaux, France. This city had an ambitious open data strategy in the transport domain during the last few years, which resulted in the availability of all the data infrastructure needed to illustrate our approach.

A. Consumer-Only Version

First, a state-of-the art assistive application was developed following the consumer-only model, running as a standalone application on the Android platform. This application integrates the following open data and web services to provide its assistive features:

- A multimodal journey planner provided as a web service, called Navitia.io[1], which is available for the public transports of many cities in the world. This web service itself aggregates many sources of open data provided by various transport operators and city authorities or institutions to provide multimodal trips with real-time accuracy.
- Open data provided by the Bordeaux urban area authority, covering static and real-time information about the BSS infrastructure and its instant availability.
- The Google maps service, offering features for map visualisation and navigation, map annotations, geographic location search, etc.

When the passenger plans a trip from the current position to some specified position, the multimodal journey planner is used, which returns a list of proposed itineraries. Whenever the passenger selects a journey including BSS segments, the bicycle and slot availability are checked using the urban area BSS web service. If a resource shortage is found, a message is displayed to select an alternative trip. This way, the ideal trip may be recorded. When the user selects a trip and switches to the on trip mode, the trip is displayed on the map and the user is guided along it using the GPS position. This assistive application is thus similar to other available ones, and may produce the data required by our approach.

When integrating the journey planner with the BSS web service, an interoperability issue had to be solved. Namely, the names of 24% of the BSS stations were different in the two services, with no simple correspondence rule. Therefore, a transcoding table was implemented, by searching the involved station on the map to find their correspondents. This was

[1]http://www.navitia.io

possible because the total number of stations were reasonable (166 stations). Besides, other 14% of the BSS stations were absent in the Navitia.io dataset. We suspect that the latter dataset did not contain the latest development of the BSS infrastructure. This did not constitute a practical problem, because itineraries computed by Navitia.io never include these stations.

B. Mobile/Cloud Version

A second version of the assistive application was developed for implementing some of the participatory features. The client part, running on the Android smartphone platform, is essentially the one described in the previous subsection, but was extended to provide passenger data to the server. The server part, located in the cloud, was developed semi-automatically by relying on the DiaSuite model-driven toolset for developing IoT applications [3]. With this toolset, part of the Java implementation is automatically generated from an architecture-level model written in a domain-specific language (DSL). Further support is provided for testing, simulating, and deploying the application.

The server part contains a subsystem for detecting infrastructure incidents, which operates by periodically comparing the theoretical time schedules of the railway transport modes (tramway lines, in our case) with the real-time data at the corresponding stops. When significant delays are detected, they are analysed and eventually reported as a service disruption.

For every ongoing trip reported by the assistive application (client), the server maintains the passenger ID and trip in a data structure until its schedule is complete. This way, whenever an incident is detected, notifications can be sent to all the impacted passengers. When passengers receive incident notifications, it is their responsibility to trigger a trip re-computation. When the resolution of a pending incident is detected, a notification is also sent to the concerned passengers.

Whenever a ideal trip is unsatisfiable because of a BSS shortage, the miss is virtually reported to the BSS operator. Indeed, the real transport and BSS operators were not available for experiments. Therefore, reported BSS shortages are never really solved. The green assistance mode is partially implemented, by sending notifications either by the mobile data connection (in GPS-off mode) or via SMS (in offline or low-tech modes). However, as the operator's sensing infrastructure was not available, there is no progress information about ongoing trips in green mode; the server considers in this case that the initial trip schedule is respected; ongoing trips are garbage collected when they expire.

V. Challenges and Future Work

The proof-of-concept prototype described in the previous section illustrates the concept of participatory ecosystem in multimodal transports and is a good base for experimentation. However, in order to fully implement the described vision, important challenges remain to be addressed.

A. Interoperability

In the description of the prototype implementation, we already discussed an interoperability issue, that has been solved manually by establishing a correspondence between two open datasets that were named differently and corresponded to different versions of a BSS system. Such interoperability issues are not surprising given the heterogeneity of the open data offered by a wide range of actors, and they require a systematic solution, because manual fixes do not scale for several reasons. Firstly, they have to be reproduced upon each change in an open data version. Secondly, they may involve much bigger datasets than in our case study. Therefore, automatic tools are needed to integrate open datasets from different providers, and repeatedly perform maintenance of the result. Actors such as Navitia.io perform this kind of data integration, but they do not cover all the data spectrum. In our case study, a tool for aligning datasets corresponding to geographically-situated objects should be adapted and used. More generally, standardisation efforts in the intelligent transports domain, such as the efforts of the ETSI ITS committee[2], are most promising for solving this kind of issues.

B. Scalability

In large urban areas, millions of passengers daily perform multimodal trips. During rush hours, this may generate thousands of events per second: mostly ticket validations coming from the operator sensing infrastructure, but also user trips that start, end, or are being recomputed. The technology used to implement the server part must be able to cope with data arriving at such pace.

As far as our prototype is concerned, we plan to switch to an evolution of the DiaSpec DSL called DiaSwarm [12], which is specially designed for orchestrating masses of sensors and actuators providing data with high frequency, and uses big data computing technologies (either batch- or streaming-style) to parallelise computations.

C. User Acceptance

Participatory ecosystems are subject to subject involvement. In our case, the main question is whether passengers may accept or not to communicate their identity and/or travel data to the transport operator. In terms of identity, we showed that different privacy tradeoffs are possible, and in most scenarios trips can be followed anonymously. When the ID used contains private data, such as the cellphone number or a nominative transport pass, the acceptance question becomes more relevant. However, many passengers are already using nominative transport passes, and therefore the transport operator can already trace them throughout its infrastructure. The only extra information supplied by the assistive application is their final destination, and eventually the unfeasible ideal trip.

Based on a previous acceptability study performed in the Instant Mobility european project [6], it turns out that most passengers in multimodal transports accept to be followed by

[2]http://www.etsi.org/

the operator in exchange of an improved level of service: more than 90% would accept to provide their real-time location, and 84% to record their trips. However, strictly speaking, this kind of study should be re-conducted specifically for a participatory assistive application to check that the extra information provided does not change the passengers decision. We plan to conduct such an acceptability study in our inter-disciplinary team containing social science experts.

D. Experimental and Simulation-Based Validation

We are currently setting up a framework to experiment our participatory assistive application with the real transport operators of the Bordeaux urban area within a recently created local lab on Intelligent Transport Systems, part of the regional Living Lab Aquitaine. This will allow us to implement and test the missing parts in our prototype, to validate our hypotheses, such as the average anticipation time for BSS needs, and to measure key performance indicators such as the impact of anticipated needs on BSS repositioning or the impact of the other mentioned optimisations.

There are obvious advantages of performing part of such experimental work using simulators. For instance, we would like to study the relative gains of using the "exact" anticipated BSS needs, when compared to need prediction models [17], [8], [9], for existing bicycle repositioning algorithms. Unfortunately, the experiments reported in the literature are not directly usable for that purpose as the corresponding algorithms and modelling settings are not openly available. It would be most useful if open testbed frameworks were made available at least for common transport subsystems such as a BSS, for which algorithmic surveys begin to exist [7].

VI. Related Work

We divide related work in three categories: community-based ecosystems, ICT for Sustainability, and management of BSS systems.

a) Community-based ecosystems: Data ecosystems related to ours are enabled by other assistive applications in the transport domain, such as the Waze community-based traffic and navigation application[3]. In such ecosystems, car drivers share real-time information about accidents, road hazards, and traffic jams. The assistive application is essentially a GPS navigator extended to also produce data about the current vehicle. Some user data, such as the current position and speed is produced automatically, and is used by the community service to detect traffic jams and notify other drivers about them. Other data may be produced manually by the drivers, such as the cause of a traffic jam. At first sight, our assistive application concept may be seen as a direct transposal of the Waze concept to the domain of public transportation. However, the major difference in the transport ecosystem we are studying is that it includes the transport operators. Stemming from this design choice, the ecosystem is able to actively react on users demand, rather than only informing users about current conditions and directing them to cope at best with the current infrastructure constraints. In contrast, Waze drivers data is not used for instance to modify the management of traffic lights, unless city/road operators are included some day in the ecosystem. Another essential benefit of including the public transport operator is to factorise position-based computations into the cloud by relying on the operator's existing sensing infrastructure to individually locate and guide passengers. This sustainability optimisation would not be possible on the road, where itineraries are free rather than following pre-defined lines and checkpoints.

Some assistive applications for public transports [5], [14] also include community-based features, such as signalling overcrowded vehicles or other incidents therein that are not signalled by transport operators themselves. These community features, requiring manually producing data, constitute a collaboration between passengers to cope with transport incidents; they are orthogonal with the collaboration between passengers and operators to optimise the transport and the assistive application itself. Thus, the kind of participatory ecosystems we presented enables complementary optimisations that are not possible in pure community-based ecosystems.

b) ICT for Sustainability: In a more general perspective, our approach belongs to the field of ICT (Information and Communication Technology) for Sustainability, which covers two distinct domains [10]:

- Sustainability in ICT: Making ICT goods and services more sustainable over their whole life cycle, mainly by reducing the energy and material flows they invoke.
- Sustainability by ICT: Creating, enabling, and encouraging sustainable patterns of production and consumption.

Indeed, our assistive application concept belongs to both above subdomains, firstly by decreasing power consumption in certain usage scenarios, and secondly by enabling optimisations of the transport system. The most radical scenarios, consisting in using a cellphone or a smartphone offline could be related to the "sustainability by low-tech" trend recently advocated by some authors [1].

c) Management of BSS systems: Many approaches exist aiming to predict the usage of scarce resources in a BSS system, in order to help the service providers schedule the manual bike re-dispatch. Giot and Cherrier [8] presents a model predicting the amount of bicycles at each station for the next 24 hours at a frequency of one hour. Zhang *et al.* [18] monitor the bike usage to infer the potential destinations and duration of individuals' trips in advance (e.g., at the moment when individuals borrow a bike and start their trips). Yexin *et al.* [19] predict the number of bikes that will be rented from/returned to each station cluster in a future period, using a bipartite clustering algorithm to cluster bike stations into groups, formulating a two-level hierarchy of stations. Han *et al.* [9] also predict bicycle demand of each station using a spatiotemporal network filtering process. Other algorithms for managing BSS based on predictive information are surveyed in [7].

[3]https://www.waze.com

With respect to these statistically-based predictive approaches, our assistive application concept brings “exact” anticipated information by studying the BSS problem in the more general setting of public multimodal transports. Note however that the anticipated needs provided by the assistive application are subject to incidents during the ongoing trip, and may finally not come true. It would be interesting to comparatively study the accuracy of statistics-based and plan-based predictions, in practice.

Other prediction models are clearly complementary to the information produced by an assistive application. For instance, Chen *et al.* [4] present a model to predict the waiting times for the next available bicycle if the current availability is zero. Such wait time predictions could be used by the assistive application to mark these trips as feasible-with-waiting (rather than unfeasible), and to inform the transport operator about the need to reduce this waiting time via adequate actions, if possible.

VII. Conclusion

One commonly used definitions of a smart city was formulated by the Gartner advisory company in 2011: “A smart city is based on intelligent exchanges of information that flow between its many different subsystems. [...] The city will act on this information flow to make its wider ecosystem more resource-efficient and sustainable.” Indeed, the whole research on smart cities is about exploring concrete instances of information ecosystems. This paper presented a few concrete steps towards building such an ecosystem in multimodal transports, by relying on participatory features. In particular, we detailed some concrete optimisation opportunities enabled by specific pieces of information passed from passengers to transport operators. This passenger information can be produced by an assistive applications with no extra effort from its users. The optimisations improve the sustainability of the whole system by decreasing power consumption, in several scenarios corresponding to different privacy/sustainability tradeoffs. Other optimisations aim improving the efficiency of the transport itself: during a trip by resolving resource shortages and by better compensating the incidents; and at longer term by directly measuring unsatisfied resource requests in the current infrastructure. Thus, this kind of participatory ecosystem involving the transport operators goes beyond what can be done with only community-based ecosystems.

Acknowledgments

The author would like to thank Milan Kabac for co-supervising the student team that implemented the VIP prototype, for providing them training and support on the DiaSuite technology and tools, and for many enthusiastic discussions during this project. Thanks also go to Charles Consel, as well as other member of the Phoenix team, for fruitful discussions that helped in orienting and shaping the discourse. Finally, special thanks to the 8 team students themselves for choosing and working out this subject.

References

[1] Philippe Bihouix. "The low-tech age: Towards a technically-sustainable civilisation". ISBN 978-2021160727. Seuil, 2014. (in french)

[2] T. Carpenter, S. Keshav and J. Wong, "Sizing Finite-Population Vehicle Pools," in IEEE Transactions on Intelligent Transportation Systems, vol. 15, no. 3, pp. 1134-1144, June 2014.

[3] Damien Cassou, Julien Bruneau, Charles Consel, Emilie Balland. "Towards a Tool-based Development Methodology for Pervasive Computing Applications". IEEE TSE: Transactions on Software Engineering, IEEE Computer Society, 2012, 38 (6).

[4] Bei Chen, F. Pinelli, M. Sinn, A. Botea and F. Calabrese, "Uncertainty in urban mobility: Predicting waiting times for shared bicycles and parking lots," 16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013), The Hague, 2013, pp. 53-58.

[5] https://citymapper.com

[6] Nathalie Dupuis. "Acceptability and social community issues for ride sharing and multimodality success". Nomadic workshop, Lyon, 15 November 2012. http://fr.slideshare.net/NathalieDubus/nomadic-workshop-lyon-15-november-2012-3.

[7] Damianos Gavalas, Charalampos Konstantopoulos, and Grammati Pantziou. "Design and Management of Vehicle Sharing Systems: A Survey of Algorithmic Approaches". In "Smart Cities and Homes: Key Enabling Technologies", M.S. Obaidat and P. Nicopolitidis (Eds.), Elsevier Science, in press. 2015.

[8] Romain Giot, Raphael Cherrier. Predicting Bikeshare System Usage Up to One Day Ahead. IEEE Symposium Series in Computational Intelligence 2014 (SSCI 2014). Workshop on Computational Intelligence in Vehicles and Transportation Systems (CIVTS 2014), Dec 2014, France.

[9] Yufei Han, Etienne Come, Latifa Oukhellou. Toward Bicycle Demand Prediction of Large-Scale Bicycle-Sharing System. TRB 93rd Annual meeting, Jan 2014, France. TRANSPORTATION RESEARCH BOARD. https://hal.archives-ouvertes.fr/hal-01053016

[10] Hilty, L.M., Aebischer, B.: ICT for Sustainability: An Emerging Research Field. In: Hilty, L.M., Aebischer, B. (eds.) ICT Innovations for Sustainability. Advances in Intelligent Systems and Computing 310, Springer International Publishing. 2015.

[11] Ixxi, RATP Group. "Detailed analysis of public transport journeys in the Paris area". September 2014. (in french) http://www.ixxi-mobility.com/sites/default/files/Etude%20déplacements%20en%20Ile%20de%20France%20Ixxi_2.pdf

[12] Milan Kabác, Charles Consel. "Orchestrating Masses of Sensors: A Design-Driven Development Approach". 14th International Conference on Generative Programming: Concepts & Experience (GPCE'15), Oct 2015, Pittsburgh, PA, USA.

[13] M. Naphade, G. Banavar, C. Harrison, J. Paraszczak and R. Morris, "Smarter Cities and Their Innovation Challenges," in Computer, vol. 44, no. 6, pp. 32-39, June 2011.

[14] http://moovitapp.com

[15] Susan A. Shaheen; et al. (October 2014). "Public Bikesharing in North America During a Period of Rapid Expansion: Understanding Business Models, Industry Trends and User Impacts" (PDF). Mineta Transportation Institute (MTI). http://transweb.sjsu.edu/PDFs/research/1131-public-bikesharing-business-models-trends-impacts.pdf

[16] ORS Ile-de-France. "Health and work in Paris area. Results of the health survey 2010 by the INPES". October 2013. (in french) http://www.ors-idf.org/dmdocuments/2013/FicheBaroSanteTravai.pdf

[17] Divya Singhvi, Somya Singhvi, Peter I. Frazier, Shane G. Henderson, Eoin O' Mahony, David B. Shmoys, Dawn B. Woodard "Predicting Bike Usage for New York City's Bike Sharing System". Cornell University, Association for the Advancement of Artificial Intelligence, Palo Alto, CA: 2015. http://nacto.org/references/predicting-bike-usage-for-new-york-citys-bike-sharing-system/

[18] Jiawei Zhang, Xiao Pan, Moyin Li, Philip S. Yu. "Bicycle-Sharing System Analysis and Trip Prediction" IEEE MDM'16 (17th IEEE International Conference On Mobile Data Management). 13 - 16 June, 2016. PORTO, PORTUGAL.

[19] Yexin Li, Yu Zheng, Huichu Zhang, and Lei Chen. 2015. Traffic prediction in a bike-sharing system. In Proceedings of the 23rd SIGSPATIAL International Conference on Advances in Geographic Information Systems (GIS '15). ACM, New York, NY, USA. 2015.