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# Towards novel public transport services via real-time optimisation of demand and supply with traveller incentivisation

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**Abstract** Developments in intelligent transportation systems and information and communication technology allow significant improvements of public transport making it more competitive to the emerging app-based personal mobility services. In this paper we demonstrate how demand responsive transport services—characterised by flexible routing and scheduling—can complement conventional timetable-bound bus operations in order to offer seamless inter-modal door-to-door mobility. The paper discusses technological aspects, as well as associated privacy issues together with potential solutions.

**Keywords:** Public transport, demand responsive transport, smart cities.

## 1. Introduction

*Public transport* (PT) has no alternatives when it comes to urban areas with high mobility demand. However, complementary mobility solutions allow addressing the problem of the last mile as well as they may alleviate peak-time excess demand. One of such solutions is called *demand responsive transport* (DRT). It is a type of PT operated by smaller-size vehicles and characterised by flexible routing and scheduling. Unfortunately, in recent years the main discussion concerning PT was largely neglecting the disruptive innovation called personal mobility represented by app-based mobility providers, such as Uber, which, thanks to high utilisation of vehicles, allows low-fare door-to-door on-demand services available any time [1]. Consequently, the existing DRT services are currently unconnected with conventional timetable-bound PT services, thus they cannot offer seamless intermodal travel experience. Both services suffer from lack of real-time information about *demand* (trip plans of travellers) and use in limited way information about *supply* (bus locations and traveller counts). Moreover, *communication* with travellers is very limited. However, by taking advantage of the emerging *information and communication technologies* (ICT), PT services have a chance to compete with app-based mobility providers. Thanks to the emerging technologies large amount of unique PT-related data is now available to PT operators. It includes conventional information about bus locations, traveller counts, and general traffic conditions, as well as new sources coming from travellers (smart phones), and vehicles (probe data). Sources of such data are *automated vehicle location* (AVL), *automated passenger counting* (APC) systems, and smart phones. Moreover, the shift towards electronic fare collection systems gives PT operators access to information about trips undertaken by travellers [2]. In addition to identifying travel demands, they allow *personal navigation services* (PNS), which assist travellers in their trip [3]. In this paper we demonstrate how these technologies can be used to offer seamless intermodal travel experience combining fixed and flexible PT services. The rest of this paper is structured as follows. Section 2 introduces the state of the art. Section 3 describes our solution. Finally, Section 4 concludes the paper.

## 2. State of the art

This section is divided into three parts. We start with an overview of transportation systems with a focus on traveller/vehicle-related data. This is followed by a survey on latest developments in open platforms for PT services and predictive data analytics techniques. Finally, we conclude the review of privacy protection research on location data.

**Part 1—Transportation systems and related data:** The emerging concept of connectivity provided by *connected vehicle* (CV) technology allows to switch from currently used standalone *intelligent transportation system* (ITS) systems to the *cooperative ITS* (C-ITS) paradigm, where mobility actors not only can collect and share information, but also cooperate in order to increase mutual benefits [4,44,45]. It also enables direct communication between all road participants, and provides them with access to various types of data. There are three primary sources of transportation data: *mobile phones of travellers*, *private vehicles*, and *buses* (see Figure 1).

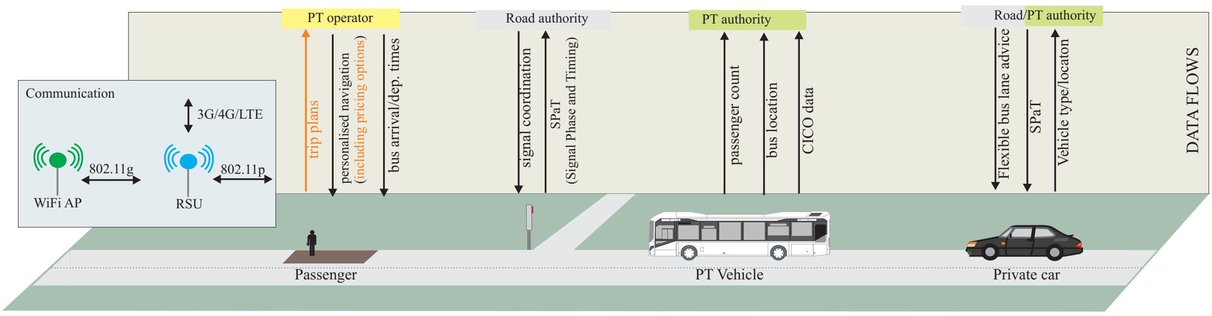



**Figure 1 Transportation data flows.**

In the near future, traffic data will be crowd-sourced by road users [5]. Information about PT operations is managed by AVL systems [6,46], complemented with APC systems [7]. The shift towards electronic fare collection systems gives PT operators access to information about trips undertaken by travellers [8,9]. These systems are based on *radio frequency identification* (RFID) and *near field communication* (NFC) standards. In addition to identifying travel demands [10], they allow *personal navigation services* (PNS). Based on AVL inputs, PNS assist travellers in their trip [11]. Their main drawback is reliance on the check-in, check-out (CICO) method for location awareness (e.g., see [9,12]). The method, even if used with contactless technologies, requires the tickets to be located within a small distance of the card reader. Therefore, in practice check-out is rarely required by the operators, while check-in is typically only required by single-use tickets. Consequently, information about undertaken trips with such a method is rather restricted.

**Part 2—Dynamic mobility systems and predictive analytics:** Software platforms are very successful in transportation management and logistics, where service providers have full control over their trucking assets, drivers and have complete information of customers' orders [13]. A number of attempts have been taken to develop similar solutions for public transport [14,15,16]. However, most of them fail to take up and achieve any reasonable penetration, mainly due to the lack of intelligent data analysis and difficulty of operating with unknown traveller route and destination demands, not having up-to-date information about transportation fleet exact location and driving dynamics, and lack of information about road conditions and from the road infrastructure. The availability of predictive data analytics is an enabler technology positioned to revolutionise management in future transportation systems, by allowing not only to rely on available historical and current-state information, which is often incomplete, but also predict the likehood of the future state of the transportation system and its participants.

**Part 3—Privacy:** Privacy of location and space, implying that individuals have the right to move in public spaces without being identified, tracked or monitored, is gaining an increasing attention in research. Research literature on achieving location privacy mainly uses location cloaking, where a user's location is cloaked by an entity called anonymiser (a third party or the user's device). In [17] the authors study a system model, which can be used to find the balance between privacy and the quality of location-based services. In their model, users can specify their location, service request and privacy requirements to the cloaking agent, which in turn produces the cloaked location and an "imprecise" service request. In this way, the service provider only knows the region where the user is, but does not know where exactly. The system Casper* [18] uses a location anonymiser to blur a user's exact location information into a cloaked area to satisfy user specified privacy requirements. The most important anonymisation technique used for privacy protection in LBSs is *k*-anonymity and its extensions (e.g., [19-22]). Normally, locations are replaced by regions covering at least k users. In order to achieve location privacy based *k*-anonymity, for instance, in [20] the authors

develop a protocol based on homomorphic encryption which can cloak a user's location in a way that there are at least *k-1* other people within the cloaked area. The idea of *k*-anonymity is extended to protect user trajectories [23] by making use of spatial properties of spatio-temporal data. Different from [23], in [24] the authors propose a method based on temporal clustering to achieve k-anonymity. To protect privacy in GPS traces, [25] proposes a technique called path-cloaking. In location tracking, Mixzones [26,27] is the main method to prevent an adversary to track the location of users, by allowing users to change their pseudonyms. The paper [28] presents an idea of sending transformed location information to the service provider, where the transformations are performed by agents interposed between users and the service provider. This technique protects user location information and movements as well. A distortion model is proposed to protect location privacy of mobile users to reach a balance between privacy disclosure and quality of service [29]. To anonymise trajectories, Domingo-Ferrer et al. [30] propose a method based on a distance measure for trajectories. In the context of electronic toll pricing systems (e.g., see [31-33]), location privacy is achieved by providing anonymity for drivers and unlinkability for travel records.
Two conclusions can be drawn from the state of the art:

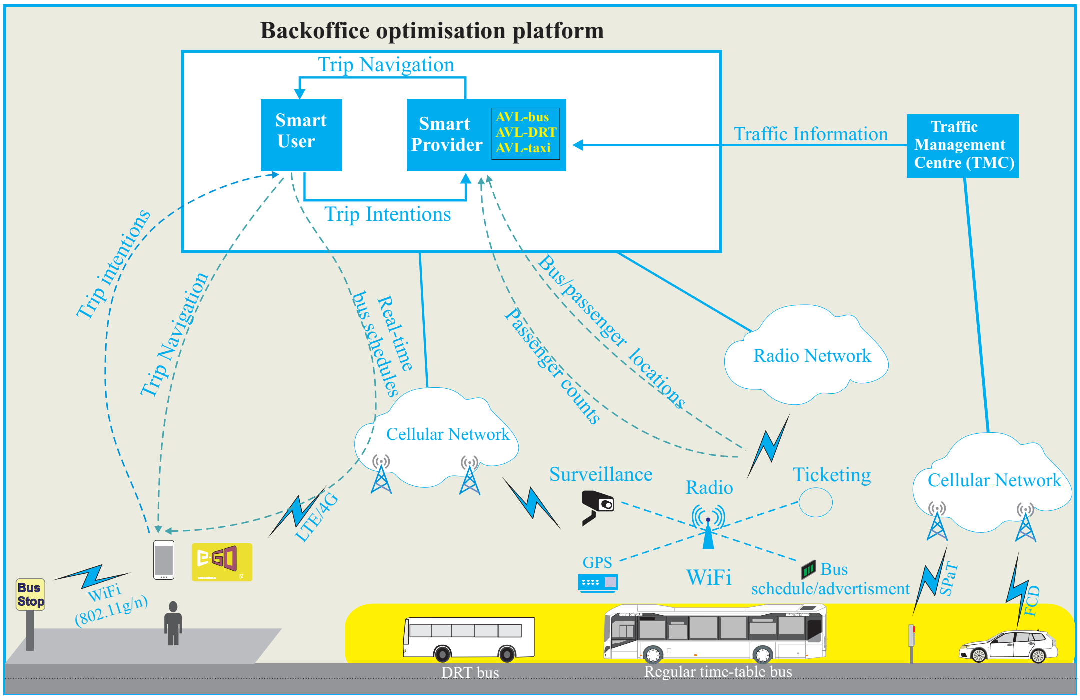
1. Knowledge about near-future traveling plans is not available to the mobility providers, while information about undertaken trips is usually limited, as it relies on the unpractical CICO method requiring physical/proximity contact between the ticket and ticket reader.
2. No techniques exist in the literature for location privacy and trajectory anonymisation, taking into account the semantics of location into account, particularly in the areas of integrated intermodal trip involving several mobility providers.

## 3. Platform overview

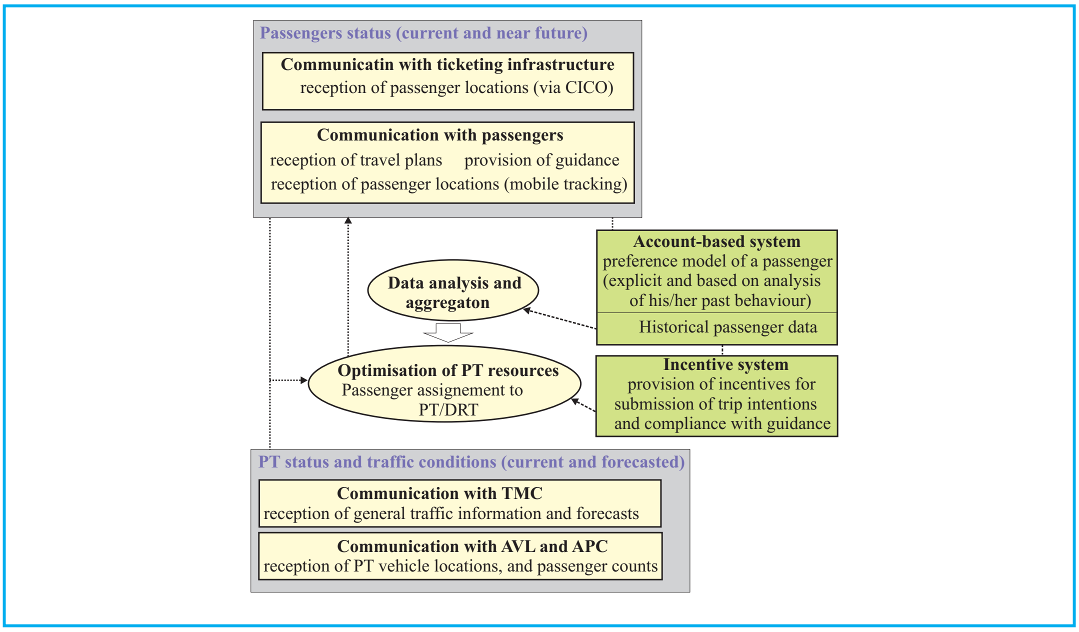
The high-level view of the proposed approach is shown in Figure 2. It has two main components referred to as a *smart operator* (SO) and a *smart traveller* (ST). The former continuously optimises PT operations by finding optimal distribution of travellers to PT services (including DRT). The latter interacts with travellers, i.e., it collects their trip plans, and provides travellers with guidance with incentives. The presented platform collects, processes, and analyses data from travellers, and PT fleet. It The plans are collected in the following ways—(a) explicit submission via mobile devices of travellers, (b) CICO events recorded by ticketing infrastructure, and (c) location data of the travellers obtained via device tracking. The ST component receives *general traffic* information from a *traffic management centre* (TMC), as well as traveller loads (from APC systems) and bus locations (from AVL systems). The proposed approach aims at the following objectives:

- **O1**: Provide efficient transportation-related data flow between the platform and travellers, PT operators and road infrastructure. Such data includes information about traveller behaviour—past, current, and expected (i.e., plans), and their location.

- **O2**: Allow real-time data processing/analysis and optimisation of traveller assignment within conventional timetable-bound lines and DRT. This implies collecting real-time data about localisation of travellers as ability to estimate travel demands in real-time.
- **O3**: Ensure security and privacy of traveller data at all stages of data collection, processing and interaction between the cloud and other actors of the transportation ecosystem.




a)




b)

**Figure 2 Overview of potential solution (a), PT back-office system (b).**

Below we give two potential scenarios of the interaction of travellers with the system. They differ in the involvement of the traveller (active or passive), in the amount of required data used by the SO component, and consequently in privacy exposure of a traveller.

**Scenario 1: "active" with traveller explicit actions:** A traveller submits via mobile phone application his/her trip plan to the SO component. The plan can be described as follows: "in 15 minutes I need transport from location A to location B". In return, SO will submit one of the two possible recommendations (referred to as *guidance*), with request to confirm his/her selection:

- **G1**: "Please use regular bus line number 10. The bus will arrive at bus stop X in 5 minutes. Next change to line 16 at bus stop Y (approximate waiting time 5 minutes). Expected total travel time is 20 minutes".
- **G2**: "DRT service can pick you up from bus stop X in 20 minutes and drop you in bus stop Z. Expected travel time is 10 minutes. Additional price surcharge is 0.5 EUR."

Scenario 1 can also involve tracking of the movement of the traveller (i.e., mobile device tracking). This means that precise location of the traveller is known to the SO, which allows further improvements as explained below (scenario extensions). The advantage of device tracking is that unlike the currently used CICO method, it does not require any activity from a traveller (CICO assumes that a traveller taps his/her card on a fare collection device). Tracking means that SO will know the time when the traveller will approach a bus stop. Let us further assume that there are two buses, which can take the traveller to his/her final destination, e.g., bus number 10 and bus number 16. The first bus is expected to arrive one minute ahead of the second, but carries many more travellers than the second (the operator is aware of that, thanks to an APC system). In this case, a new guidance can follow G1, possibly with an incentive:

**G1.2:** "The first bus (line 16) is over-crowded. Please take the second bus (line 125). Expected additional delay will be one minute. Price reduction will be 0.5 EUR."

This allows the PT operator to load-balance the use of buses (regular and DRT), which increases traveller comfort, reduces a risk of bus bunching, and increases availability of DRT. In case of recommendation G2, the service can propose modified combinations of pick-up and drop-off points.

**Scenario 2: "passive" with tracking:** SO tracks location of a traveller (with his/her prior consent). The SO then analyses traveller behaviour: based on the comparison of new information with the previously recorded patterns, the SO uses predictive analytics to automatically derive the likehood of traveller plans without requiring explicit input from the passenger. Having obtained the traveller plans, similar to Scenario 1, the SO proposes specific guidance. Below we describe methods used in the proposed platform.

**Infrastructure and Data**: The infrastructure related to data collection includes mobile applications deployed on the smart phones of travellers, AVL/APC systems, ticketing infrastructure (for CICO operations, performed using NFC or short-range radio channel), buses connected via radio network, TMC providing traffic data and GPS- or triangulation-based tracking of mobile devices of travellers. Our platform is implemented in cloud computing environment available globally and capable of executing instances of virtualized applications, as well as SO and ST functionalities. This enables us to achieve the objective O1. Travellers can be connected to the cloud using LTE, or WiFi technologies when available. WiFi coverage is already provided in most of the cities and is often offered in buses. The buses themselves can also serve as intermediary between the platform and the travellers. They can aggregate, process and relay to the cloud information about passengers and their travel intensions. In addition to simple collection and processing of such information, buses can provide the environment to execute certain optimisation tasks from the cloud. This has obvious benefits and advantages in having more reliable and up-to-date information, as it is based on the recorded CICO events. Travellers can specify their travel demands explicitly by entering their trip plans manually using specifically designed smartphone application. This will provide precise starting and end points of the travelling route. However, travellers might not be always willing to input their travel demand every time manually. In these cases, the proposed system will predict real-time demands of the travellers by analysing a large variety of the available information including estimation of current traveller location (via CICO or device tracking), traveller profile and his/her past behaviour. CICO-based inputs provide a precise route starting point, while the destination (if not recorded by check-out operation) can be estimated based on the traveller profile and habits. In this case, the system will calculate not a single destination, but build a list of possible destinations sorted according to their priority and likehood levels.

**Smart Operator and Traveller:** The goal of these two components is to allow PT operators to reach the objective O2. Smart Operator will optimise the assignment of travellers to PT services via providing guidance by using the following information: (a) short-term traveller plans, (b) status of PT operations, (c) traffic status, and (d) traveller historical behaviour. Short-term traveller plans are either collected directly from travellers, or inferred from their location/mobility patterns in conjunction with traveller's profile and historical information. As mentioned earlier, the location/mobility patterns are obtained via mobile device tracking and/or via CICO operations. Interactions between travellers and the operator are recorded by an account-based system, in order to allow continuous reciprocity-based relation. Given the information listed above, SO will optimise traveller assignment to services. Multi-objective optimisation methods, such as well-known NSGAII and other advanced and parallel methods, such as *cooperative co-evolutionary multi-objective algorithms* [34] can be used. The proposed solution optimises multimodal transportation services jointly and generates trip direction (guidance), which is then sent to the traveller. SO also includes a system of incentives (e.g., loyalty programs or credit-based). The role of incentives is twofold: (a) to encourage travellers to submit their trip intentions, and (b) to encourage travellers to follow the provided guidance, especially when it is not optimal from the user point of view (as in the example given in the use case above in G1.2). The system of incentives plays a similar role to the marginal pricing concept proposed in [35], designed to address optimisation of route selection by vehicles. SO requires agreements with PT operators on data privacy.

The advanced engine for predictive data analytics processes information coming form travellers, buses, PT operators, taxis, road infrastructure and TMC and predicts the likehood of the future state of the transportation system and its participants in the near-future (seconds or minutes) or long-term (hours or days) time scales. The prediction about intended traveller destinations, bus driving dynamics and time spent on stops or traffic lights, deviation from the planned schedule or projected fuel consumption will be done with the help of statistical analysis and regression analyses, machine learning, neural networks and support vector machines [36]. The availability of predicted information complemented by the available historical and current-state information will allow eliminating inefficiencies, optimising routing and scheduling, billing and ticketing systems, and help maintaining the fleet.

**Privacy:** One of the main challenges of the proposed cloud computing ST (smart traveller) and SO (smart operator) systems is to guarantee location and trajectory privacy of the travellers. Ideally, travellers should have full control of their location and travel information, and should be aware of how such information is collected, used, processed and disclosed. However, the potential abuse of traveller location information is a major concern for large-scale deployment of smart transportation systems. We focus on different privacy protection solutions depending on what location data will be collected, and how location data will be used and analysed within our system.

Data collection in our methods requires considering traveller location privacy at the microscopic level. We need to not only perform proper anonymisation on the collected data but also develop effective privacy-preserving techniques to protect travellers' location privacy. Based on our previous on query privacy [37, 38, 39] and location privacy [40], we will investigate semantics of the location data to perform better location cloaking to achieve required location precision for SO and ST. For instance, we need to differentiate bus stops and home area (the former is public and the latter is rather private).

Data analysis: Analysing spatio-temporal data is an essential socio-economic activity that enables the proposed system to take solid decisions and improve the current DRT business models. However, it also raises serious privacy concerns as location-aware applications at the microscopic level do. Traveller trajectory anonymisation problem is addressed from a data mining perspective to achieve a good balance between privacy and utility. On one hand, traveller trajectories need to be anonymised considering features like physical location, speed of movement, uncertainty, and more importantly, location semantics. On the other hand, based on the existing techniques [41-43], new traveller mobility profiling techniques, similarity metrics for taking into account location semantics need to be developed to enable the main purposes of SO and ST.

We approach the objective O3 by studying adversarial models and scenarios in location-aware applications and trajectory data publication, and extending them by taking into account semantics of location data. For the resulting adversarial models, new privacy-preserving techniques addressing each of these models are designed. We consider spatio-temporal databases where the relation between traveller and trajectory is one-to-many (i.e. travellers travel on many different routes), rather than one-to-one as is usually the case in the literature. This gives rise to new and useful utility properties as well as a revision of current adversarial models and privacy threats. Formalisation of such privacy threats together with the development of privacy-preserving techniques is also analysed.

## 4. Summary

PT operators are now facing an increasing pressure from new players in the mobility market, such as Uber or Lyft. Novel transportation services, such as the UberHop, directly compete with bus services. In this paper we demonstrated how PT services can compete and successfully address new challenges by taking advantages of the emerging information and communication technologies. The new seamless and convenient mobility services are not standalone, but rather are evolution of the existing services provided by PT networks towards app-based paradigm. In the presented framework conventional large-capacity fixed timetable lines, constituting the core of the system, are complemented with flexible, in terms of the pick-up and drop-off locations, demand responsive services.

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