Moving cities forward: how Galileo satellite technology can advance urban mobility

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Abstract

Accuracy, integrity, and continuity of the geolocation signal in complex urban environments are key features to enable new mobility services in the smart city context. Galileo is the European Global Navigation Satellite System, and along with the Satellite-Based Augmentation System EGNOS, constitutes Europe's satellite navigation programme. Galileo provides improved positioning and timing information with significant positive implications for many services and users. The system has been operational since December 2016 and can be used in combination with GPS satellites (or any other constellation) via multi-constellation receivers, already a widespread market solution. This paper reports on the status of awareness and application of Galileo technology in the urban mobility and public transport sector and provides evidence of Galileo's benefits based on the analysis of real-life applications in the bus and shared mobility domain.

Keywords: *Galileo; GNSS; space data; urban mobility; public transport*

1. Introduction

The ARIADNA project[1] (2019-2021) is committed to support the adoption of the European Global Navigation Satellite Systems (EGNSS) for public transport and urban mobility solutions by raising awareness on Galileo and EGNOS (European Geostationary Navigation Overlay Service) benefits, and its superior technical features, among key stakeholders of the mobility ecosystem, namely decision-makers, public transport operators and authorities, setting the framework for a fruitful cooperation with technology providers, start-ups and academia at global level.

ARIADNA has received funding from the EUSPA (European Union Agency for the Space Programme) under the Horizon 2020 Research and Innovation Programme, and to some extent, can be considered as a natural continuation of the Galileo for Mobility project[2] (2017-2020). Also funded by the EUSPA, Galileo for Mobility investigated the introduction of Galileo technology in the Mobility as a Service (MaaS) context, by analysing the users' needs in terms of geolocation and demonstrating the benefits of Galileo through real-life pilot demonstrators

[1] *Awareness Raising and capacity building Increasing ADoption of EGNSS in urbaN mobility Applications and services*. http://ariadna-project.eu/
[2] *G4M: Fostering the adoption of GALILEO for Mobility as a Service.* https://cordis.europa.eu/project/id/776381/es

of shared mobility services. Continuity among the two projects is ensured by the consortium composition and the involvement of mobility stakeholders to support the project's vision and ambition.

With the urban mobility landscape evolving faster than ever, the use of satellite navigation technologies for geolocation of vehicles and users represents a key enabler for most of the new services. When moving around the city using different routes and means of transport, knowing your position, and that of the vehicle you are using, is essential. To accurately define those, it is important that geolocation is readily available and as much accurate as possible, as it also allows for real-time passenger information, estimated time of arrival and information on eventual disruptions. It is for these reasons that many transportation bodies factor in geospatial technology when defining their urban mobility plans and public procurement processes.

Until recently, GNSS users had depended on non-civilian American GPS, Russian GLONASS, or Chinese BeiDou signals. The European Galileo programme stands alone as the world's unique option for GNSS under civilian control. The incorporation of Galileo positively impacts all existing applications of GNSS in urban mobility services and, more importantly, it enables new ones. This is mostly accomplished through better signal accuracy —because there are in average more satellites in view, allowing for better geometry— and availability —especially in challenging environments for GNSS, such as urban canyons, where satellite signals from one constellation can get completely blocked by tall buildings; but there is another key benefit which the Galileo system, and no other GNSS currently offers: the authentication of the satellite signal. This is one of the most differentiative, added-value features of Galileo, as it has the potential to enable a whole range of applications that are not possible today.

2. The European satellite navigation programme

The Galileo space segment comprises a constellation of a total of 30 Medium Earth Orbit satellites. The current active constellation comprises of 24 satellites (Walker 24/3/1), including 6 spare satellites, to replace any failed satellite, thereby reducing the impact of failures upon quality of service. Each satellite broadcasts navigation timing signals together with navigation data providing the clock and ephemeris correction data which are essential for navigation. The space segment of the system is complemented by the ground segment to monitor the satellites, checking that they are functioning correctly and generating the navigation data to be sent to end users. GNSS receivers can receive and transform the signals into coordinates and accurate time.

Multipath errors are still one of the major error sources for conventional GNSS receivers (GSA, 2018). A multipath error is caused by the reception of signals arrived not only directly from satellites, but also reflected from the local objects in the environment. Basically, a multipath error will cause your location to be less accurately determined. One of the main benefits of Galileo is that when compared to other GNSS, Galileo has higher resiliency against multipath, meaning it will determine location more accurately. Recent tests made with Galileo-enabled devices achieved 1-2 metres accuracy in light urban environments and a few decimetres at full open sky (in which case it is easier to determine location).

Also, the Galileo system (differently from other GNSS) authenticates its satellite signals by incorporating a digital signature to the navigation data that certifies its sources. Over the last decade, the ever-increasing dependency on GNSS has raised concerns over the security of navigation services against intentional threats such as spoofing (disguising a communication from an unknown source as being from a trusted source). Some new applications and mobility services are even hard to picture becoming a reality without authenticated signals. For instance, a seamless public transport system where ticketing relies completely on the positioning data from their passengers' smartphones. An authenticated signal not only provides more robustness, but it can even serve as legal evidence of the correctness of the GNSS position for liability issues. To tackle these concerns, Galileo has just started testing the Open Service Navigation Message Authentication (OSNMA), the first-ever transmission of authentication features in open GNSS signals of a global navigation system. The Galileo OSNMA is an authentication mechanism that allows GNSS receivers to verify the authenticity of GNSS information, making sure that the data they receive are indeed from Galileo and have not been modified in any way.

The European Geostationary Navigation Overlay Service (EGNOS) is Europe's regional satellite-based augmentation system (SBAS) that is used to improve the performance of GPS. It has been deployed to provide safety navigation services to aviation, maritime and land-based users over most of Europe. EGNOS is operational since October 2009. EGNOS can enhance even further the accuracy of GPS-determined positions (and will include Galileo in the future). Trials with EGNOS have demonstrated that it provides an increase in the position accuracy (error reduced on average of 3 meters), both in urban and extra-urban environments (GSA, 2018). EGNOS is essential for applications where accuracy and integrity are critical, for example, in the aviation sector. But it also benefits numerous other market segments, for example applications related to on-road fleet management and in the near future to the deployment of connected and automated driving.

Overall, the EGNSS have enormous potential to positively impact all existing applications benefitting from satellite technologies and open the way for new application and services in the smart city context.

3. Use of space data for mobility services: current situation and future trends

One of the key objectives of ARIADNA is to identify the specific areas and use cases where Galileo can bring added value for public transport and urban mobility services. To this end, the existing knowledge on the field has been complemented with consultations with GNSS practitioners (i.e., public transport operators, public transport authorities) to understand what the most common and promising GNSS applications in their daily operations are, and the critical requirements for the quality of GNSS signals vis-à-vis the applications. Results are grouped per mode of transport or mobility service in Table 1. For the sake of clarity, the definition of the parameters is reported hereafter:

a. Availability: the percentage of time that the position or timing solution can be computed by the use.
b. Accuracy: the difference between the real and computed position or time.
c. Continuity: the ability to function without interruption once the operation has started.
d. Integrity: the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver.

Table 1: *EGNSS applications for urban mobility services and signal requirements*

Mode/ Mobility Service	**Applications**	**Critical GNSS parameters**
Train / tram	Vehicles Tracking	a., b., c., d.
	Infrastructure maintenance	a., b., c., d.
	Speed and distance regulation	a., b., c.
	Estimated time of arrival	a., b., c.
Bus	Vehicles Tracking	a., b., d.
	Depot operations	b., d.
	Driver and work shift monitoring	a., b., c.
	Commercial speed increase	a., b., c., d.
	Offer enhancement	a., b., c.
Demand Responsive Transport	Pick-up process	b.
	Increase service speed	a., b., c., d
	Driver behaviour	a., b., c.
	Validation of the route	a., b., c., d
Shared mobility	Rebalancing and charging operations	a., b.
	Vehicle appropriation alert	b., d.
	Location of vehicle and start of the trip	b.
	End of trip and billing	b., d.
	Unauthorized parking	b., d.
Ride-hailing / Taxi	Pick-up process	b.
	Driver behaviour	a., b., c.

Accurate space data is therefore vital for a wide set of urban mobility applications. This has been confirmed by a survey carried out in 2020, also in the frame of the ARIADNA project (Laborda, Moyano, 2020). Out of 70 worldwide responses (from cities, public transport operators and authorities, technology providers, and academia), the survey shows that geolocation data is the most used space data (60% of the respondents) primarily to plan, track and manage the supply of vehicles in the network as well as to check vehicles paths. Earth Observation Data (Copernicus, or other) are used by 1 out of 3 respondents; most common applications are to determine the best itinerary for any O/D, for meteorological and atmospheric pollution information, to monitor infrastructure and accessibility needs, and failure across the network.

The survey was conducted during the COVID-19 pandemic; therefore, it was possible to collect information on how the respondents see the future of mobility services in urban areas and the post-pandemic recovery phase. It is worth mentioning that the COVID-19 pandemic has drastically impacted public transport networks across the world. The impact has resulted in the decrease of farebox revenues (in some cities the reduction in patronage has surpassed 90%) and brought with it additional costs to disinfect and implement physical distancing measures in public transport vehicles and infrastructure. It has also resulted in the reduction in industrial and service production, including the halt of activities and the decrease in turnover of the supply industry (UITP, 2020). However, at a later stage in the pandemic, evidence showing that public transport is COVID-safe came, together with the evolution of public transport demand, slowly growing after confinement. In fact, despite the increasing number of cases during the COVID-19 second wave in many countries, the ridership of public transport maintains its positive trend, gaining the trust of passengers (UITP, 2020). Among the survey respondents a strong belief was observed that geolocation and earth observation data will help improve existing mobility services as well as enable new mobility services in the COVID-19 recovery phase (Figure 1 and Figure 2)

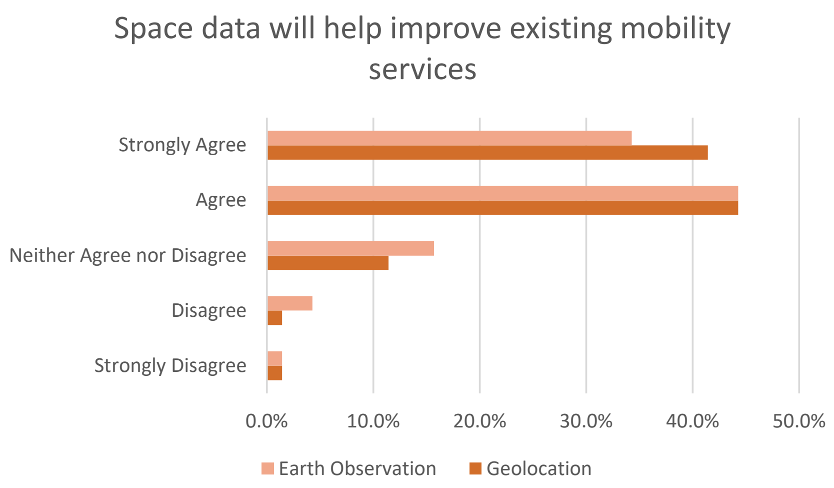

***Figure1:** Potential of space data for existing mobility services (ARIADNA survey, 2020)*

In fact, more than half of the surveyed stakeholders have plans to modernise or upgrade their transport solutions to more efficient and greener transportation as part of a post-COVID-19 recovery plan. Priorities seem to be measures aimed at promoting safer travel, updating infrastructure, and enhancing access and promotion of active travel schemes.

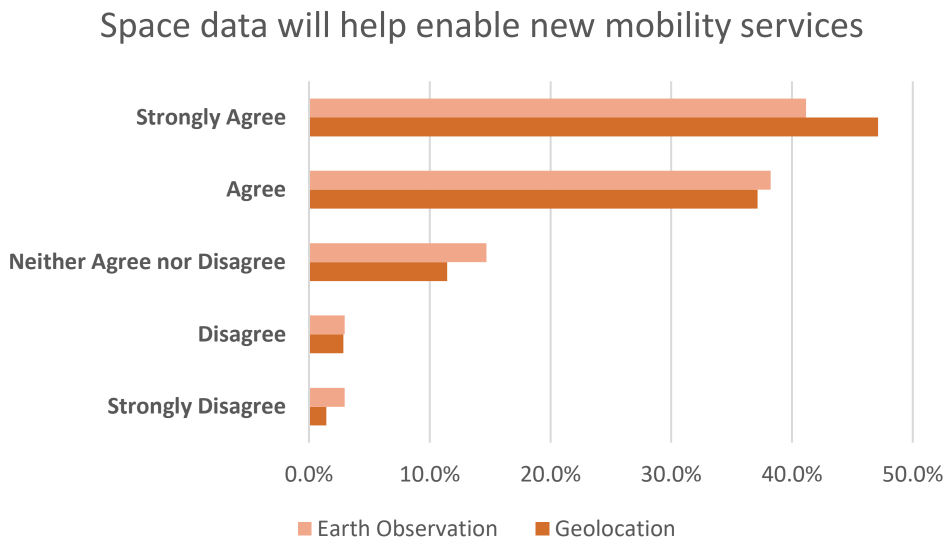

***Figure2:** Potential of space data for new mobility services and solutions (ARIADNA survey, 2020)*

The vast majority (90%) of the respondents agrees that space data is “needed” or “useful” for implementing such strategies for more sustainable cities. More specifically, space data is seen as a beneficial tool to monitor key urban mobility indicators (Figure 3), among them location and use of fleets (87%), emissions reduction (80%), and the use of streets and roads (74%).

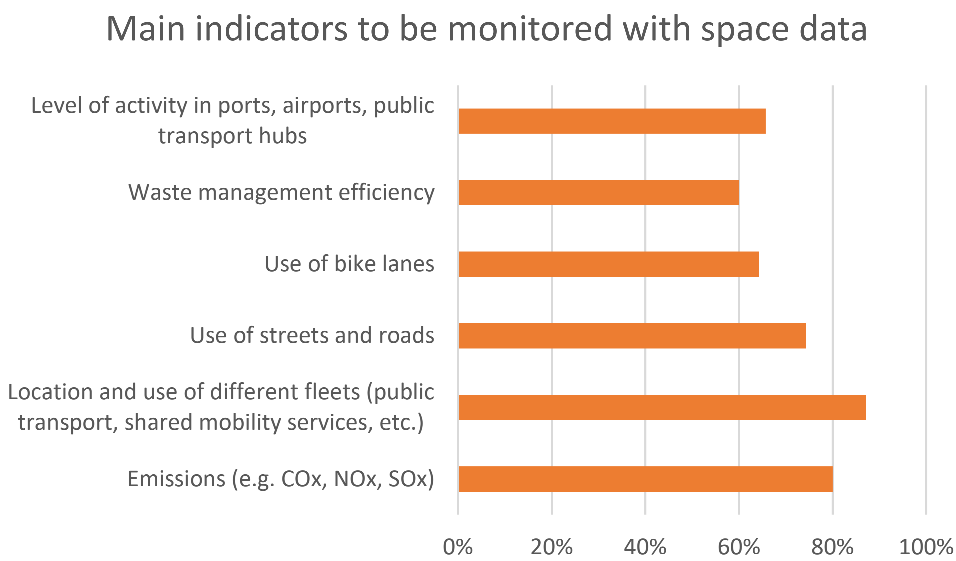

***Figure 3:** Application of space data as a support tool for more sustainable cities, multiple choice (ARIADNA survey, 2020)*

4. Analysis of use cases

The collaboration of the ARIADNA project's consortium with public transport operators and mobility providers in regular consultation activities has allowed the identification and analysis of several EGNSS applications. In the following the experience of a (i) bus operator, (ii) a scooter-sharing operator, and a (iii) Demand Responsive Transport (DRT) service, are reported.

Bus Operation

Transports Metropolitans de Barcelona (TMB), the publicly owned company operating metro, regular bus, and tourist bus services in the city of Barcelona, in 2016 renewed the on-board equipment of some of its 1,170 buses. The positioning unit embedded in the Exploitation and Information Aiding System was also replaced with a mass-market solution which integrates multi-constellation and dead reckoning capabilities. The former allows the receiver to pick up signals from all existing GNSS constellations, including Galileo. The latter is a technique which complements GNNS signals with information coming from the sensors embedded in the receiver, such as accelerometer and gyroscope, to predict the trajectory in challenging situations for GNSS technology, where GNSS signals are missing or unreliable (e.g., tunnels or underground environment).

Some tests were run by the operator before and after replacing the positioning unit, to compare the changes in performance. The tests were conducted while the bus was providing service in one of the city's bus lines, which makes their results a faithful reproduction of the situations faced by the positioning technology during operations.

Figure 4 shows position fixes recorded with the GPS-only receiver. It is clear how the GNSS signals computed by the receiver were many times off the limits of the road.

***Figure 4:** Position fixes from a bus equipped with an obsolete receiver in urban environment (source: TMB)*

In comparison, Figure 5 shows position fixes from the new receiver in the same segment of the route. The improvement is outstanding, with the receiver returning much more accurate position fixes. According to TMB, the positioning error in the most challenging sections of this road went from between 40 and 60 metres down to between 2 and 5 metres. The reference that TMB takes to calculate the error is the distance from the position fix to the lane most to the right, since that is where the bus lane is in this specific road.

Figure 5: *Position fixes from a bus equipped with a last-generation multi-constellation receiver in real operation urban environment (source: TMB)*

Similar positive results were experienced at a bus depot which has both ground-level and underground parking. With a capacity up to 440 buses, thanks to the new receiver the operator was able to accurately locate the bus at all times. In this situation the improvement comes mostly from the dead reckoning technique used by the receiver, although it is true that an accurate positioning of the bus right before entering the underground parking area contributes to a more accurate estimate of the position overall. The reasons why this improvement is relevant for the operations is because it makes it easier to find a specific bus when it must undergo maintenance tasks, such as cleaning and refuelling. It also helps drivers find the bus which they were assigned quicker, at the beginning of the day.

Overall, TMB reports a 7% improvement of the indicator that it uses to measure the amount of time that a bus is correctly positioned while in service, which is currently at 97% for the buses with the new receiver. The operator also declares being able to provide more reliable real-time information to users and a more accurate ETA.

Moped-sharing operation

Regarding the shared mobility business, evidence of the benefit of EGNSS can be found from the experience of a Spanish moped-sharing operator. In 2016, in the context of the H2020 project G-MOTIT[3], the company tested an on-board unit (OBU) which integrated a multi-constellation receiver that also made use of EGNOS. The company had experienced some problems with the reservation process in deep built environments. When a moped was parked in a narrow street, with high buildings on both sides, the geolocation provided by the old OBU was inaccurate and could sometimes lead the user to the wrong street. On the contrary, the data provided thanks to the new OBU proved to be acceptable in terms of accuracy and integrity. The test also included recordings from the moped in motion, in a semi-urban environment (Figure 6). The new OBU's position fixes (in red in the figure) were always closer to the road than the old OBU's (in purple). There were also many more of them, showing not only a significant improvement in accuracy, but in availability as well. One important factor that contributed to the accuracy improvement was the use of EGNOS, which reduced in a couple of meters the bias introduced by the system.

Figure 6: *Position fixes from a test done with a scooter equipped with a GPS-only receiver (purple) and a multi-constellation receiver (red) in a semi-urban environment*

Demand Responsive Transport operation

The third application analysed refers to a Demand Responsive Transport (DRT) service currently in operation[4] in Cervelló, a small town in the metropolitan area of Barcelona. The operator tested two different tablets for the driver, in order to compare the positioning performance of each. The tablet is used to navigate the driver through the route —which changes according to demand— and to show users the bus position and ETA in real time.

The test, which took place at the beginning of 2020, was split in two phases: a first one using a Galileo-enabled tablet, and a second one using a GPS-only tablet. The analysis was made on a

[3] *Galileo-Enhanced MOTIT: an electric scooter sharing service for sustainable urban mobility.* http://gmotit.pildo.com
[4] http://www.nemi.mobi/

route (Figure 7, left) which was repeated many times by the DRT service during lockdown, when there were very few regular users and the stops requested were always the same.

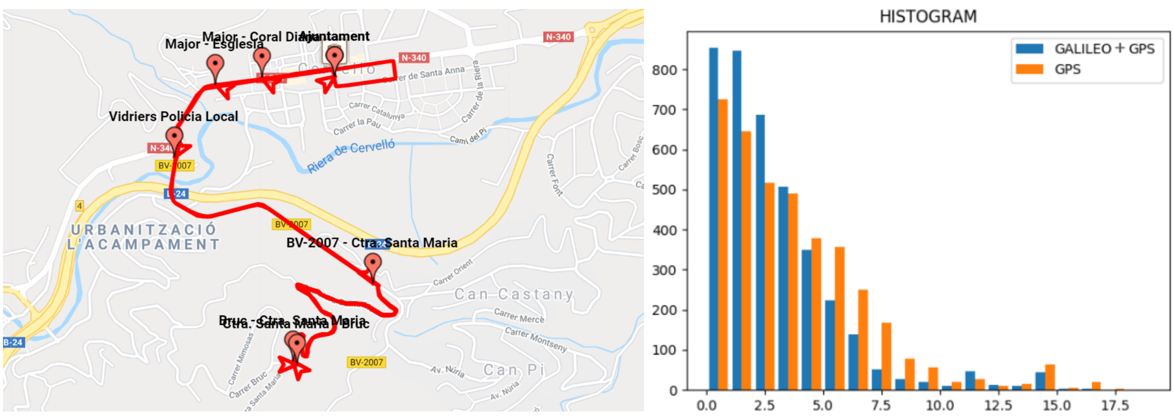

Figure 7: Error samples from a GPS-only receiver and a multi-constellation receiver (histogram) equipped on a DRT bus performing the same route (image)

In order to assess the accuracy of the receiver in each tablet, every computed position was matched to the nearest road and its error (distance to the road) was calculated. The histogram on the right side of Figure 7 groups the number of error samples (Y axle) by distance in metres (X axle). Since the error samples from the Galileo-enabled tablet outnumber the ones from the GPS-only receiver as the error becomes smaller, it can be concluded that the multi-constellation receiver was able to provide a much more accurate GNSS signal.

5. Conclusions

Galileo-enabled mass-market receivers have become widespread and are available at very competitive costs. 76% of receivers on the market are multi-constellation (i.e., compatible with at least two different constellations), and 52% are capable of working with signals from all constellations [1].

Beyond service-specific applications, when Galileo-enabled mobile devices become the norm, public administrations will be able to access more insightful aggregated mobility data thanks to the improvements in accuracy and availability enabled by EGNSS. For instance, it would be easier to differentiate with which means of transport users are travelling, the moment when they transfer to a different means, and how many times they transfer during the trip.

In order to support the adoption of multi-constellation receivers the ARIADNA consortium has developed a set of software and hardware tools to showcase in real time the difference in positioning performance between a Galileo enabled or disabled receiver, in different configurations. This set, Galileo Demo Kit (GDK), consists of 3 components:

- The GDK Box, a device for data acquisition designed to be easily installed into any vehicle for demonstration purposes. This device is to acquire and transmit GNSS data to a Web Server.

- The GDK Web Server, a cloud service aimed at monitoring GPS and Galileo performances at local level. Thanks to an easy-to-use interface, the web server can support mobility operators in their daily operations by visualising real-time and aggregated results from collected data. A web server screenshot is shown in Figure 8.
- The GDK Operator Tablet, which aims to provide guidance to the operator during the execution of a demonstration route.

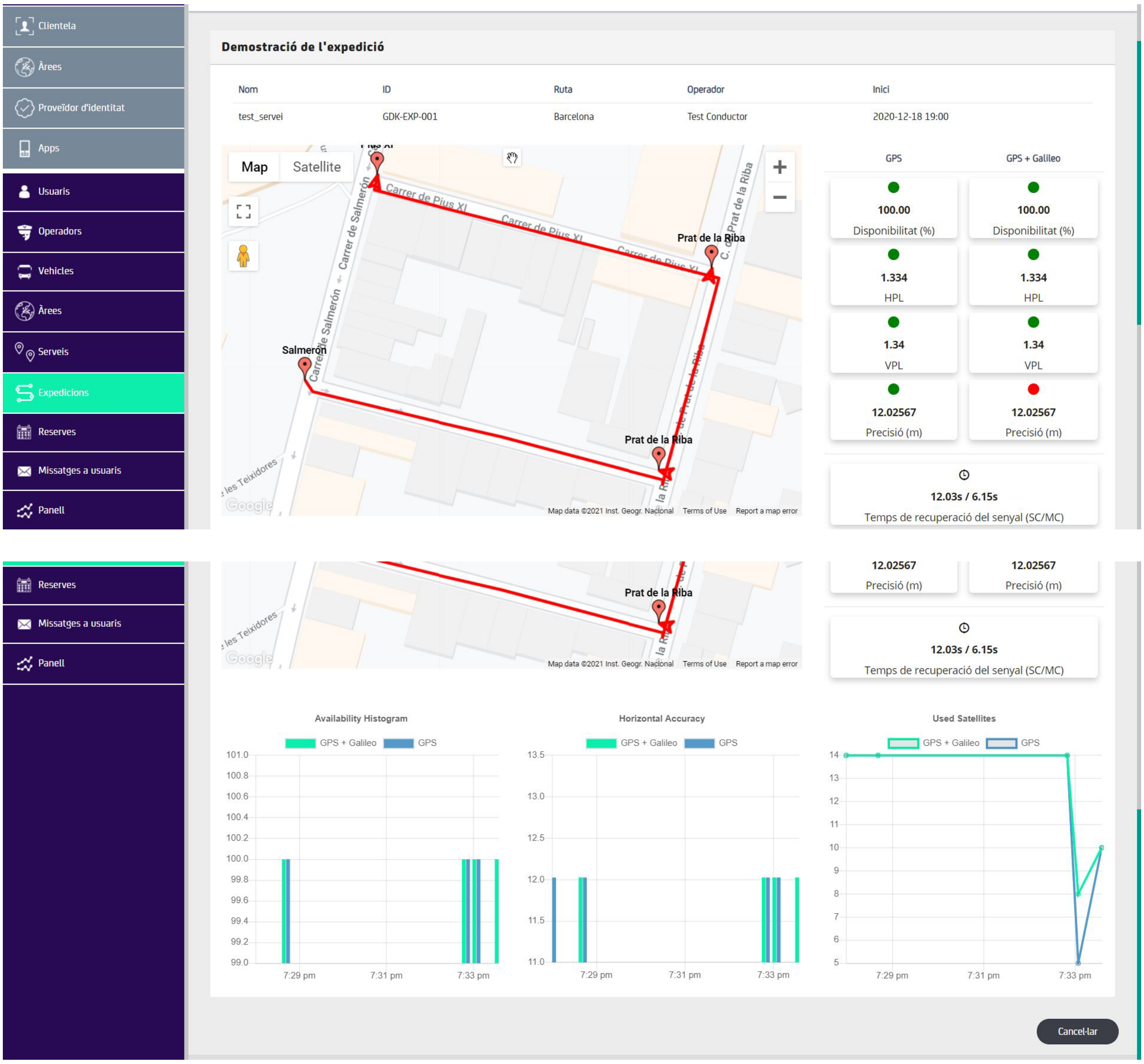

__Figure 8__: Interface of ARIADNA's Galileo Demo Kit Web Server

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References

1. European GNSS Agency, (2018). Recommendation of the European GNSS Agency (GSA) on the benefits of EGNOS and Galileo receivers for public transport
2. European GNSS Agency (2020), GNSS User Technology Report
3. Moyano, V., Laborda J. (2020). The Role and Challenges of GNSS for Urban Mobility and Public Transport. ARIADNA Project Deliverable
4. Paniagua, S. (2020). White Paper: EGNSS technology in Urban Mobility and Public Transport. ARIADNA Project Deliverable
5. UITP, (2020). Knowledge Brief, COVID-19 pandemic
6. UITP, (2020). Policy Brief, Public Transport is COVID-19 safe