European Union Agency for the Space Programme

REPORT ON PUBLIC TRANSPORT USER NEEDS AND REQUIREMENTS

Outcome of the European GNSS User Consultation Platform

June **2021**

www.euspa.europa.eu

Reference:

GSA-MKD-RL-UREQ-A11400
Issue/Version: 1
Date: 28/04/2021

Change Log:				
WFID	**Issue/ Version**	**Changes & Pages Affected**	**Author**	**Date**
	0.1	Initial draft	VVA & FDC	19/03/2021
	0.2	Updates to emphasise traditional Public Transport	VVA & FDC	28/04/2021
	1.0	Acceptance and header amendments	EUSPA	29/04/2021

TABLE OF CONTENTS

TABLES AND FIGURES

Tables

Figures

01 INTRODUCTION AND CONTEXT OF THE REPORT

GNSS is long past a simple navigation device for vehicles. In fact, the use of GNSS-based technologies is increasingly penetrating in the different aspects of people's lives and activities, ranging from transportation, to agriculture, smart applications and many more. Within transportation, GNSS has been widely used in road, rail and maritime transport for several years now, with the range of its applications constantly growing and ranging from safety-critical ones to Smart Mobility, with increasingly demanding user requirements.

When it comes to Public Transport, although GNSS is not as widely used as in the other transport domains, there has been observed a clear trend for its increasing use not only by the so-called traditional public transport means, but also by the innovative ones, such as shared mobility solutions. Management of public transport fleet, real-time passenger information, driving aids, transport on demand, autonomous mobility and Mobility-as-a-Service (MaaS) are only some of the possible applications through which GNSS can bring added value to the Public Transport. With an important list of applications and an increasing use of GNSS-based solutions in this domain, there is a growing need to define the user requirements and to further work on achieving them, to ensure that the GNSS applications in Public Transport correspond to the demanding user reality.

The User Consultation Platform (UCP) is a periodic forum organised by the European Commission and EUSPA involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers, application developers and the organisations and institutions dealing, directly and indirectly, with Galileo and EGNOS. The event is a part of the process developed at EUSPA to collect user needs and requirements and take them as inputs for provision of user driven Galileo and EGNOS services. In this context, the objective of this document is to provide a reference for the European GNSS Programmes and for the Public Transport community reporting periodically the most up-to-date GNSS user needs and requirements in the Public Transport market segment. This report is considered a "living document" in the sense that it will serve as a key input to the next UCP event where it will be reviewed and subsequently updated. The UCP will be held periodically (e.g. once per year) and this report will also be periodically updated, to reflect the evolution in the user needs, market and technology captured during the UCP.

The report aims to provide EUSPA with a clear and up-to-date view of the current and potential future user needs and requirements in order to serve as an input to the continuous improvement of the services provided by the European GNSS systems and their evolutions.

Finally, as the report is publicly available, it serves also as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of location technologies.

> The use of GNSS-based technologies is increasingly penetrating in the different aspects of people's lives and activities

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by combination of several signals and sensors. Therefore, the report does not represent any commitment of the European GNSS Programmes to address or satisfy the listed user needs and requirements in the current or future versions of the EGNSS services.

1.1 METHODOLOGY

The following figure details the methodology adopted for the analysis of the Public Transport user requirements.

As presented in the figure 1, the analysis performed under this project was split in two main parts:

- First, a desk research-based analysis was performed to identify the main GNSS applications for Public Transport, the key drivers for their performance requirements together with the main requirements, etc.

Figure 1: Public Transport User Requirements Methodology

1

Desk research

Identification of main applications and functions that they perform

- Based on desk research
- Based on previous projects

Segmentation of applications

- Classification of applications
- Definition of the main performance criteria for different applications

Definition of the functions and performance required for each application

- Definition of GNSS use in Public Transport
- Definition of the prospective GNSS use in Public Transport
- Definition of GNSS limitations for Public Transport
- Definition of the drivers for user requirements in Public Transport

2

Stakeholder consultation

User Consultation Platform

- Validation of the requirements during the Public Transport User Consultation Platform
- Finalisation of the initial User Requirements for Public Transport

- This was followed by an analysis of the outcomes of the Public Transport User Consultation Platform that took place in December 2020, in order to validate and fine-tune the analysis performed through desk research.

The steps described above have resulted in the outcomes that are presented in detail hereafter.

1.2 SCOPE

This document is part of the User Requirements documents issued by the European GNSS Agency for the Market Segments where Position Navigation and Time (PNT) play a key role. Its scope is to cover user requirements on PNT solutions from the strict user perspective and the market conditions, regulations, and standards that drive them.

Therefore, the document is structured as follows: an overview of the main market trends in Public Transport (section 4), followed by a detailed analysis of GNSS user requirements (section 5). The section on the user requirements is structured as follows:

- Sub-section 5.1 identifies and defines the main GNSS techniques used in Public Transport, the main applications, existing and upcoming EU regulations in the area, performance parameters and defines the application categories.
- Sub-section 5.2 lays out the prospective use of GNSS in Public Transport.
- Sub-section 5.3 describes the main limitations of GNSS in Public Transport.
- Sub-section 5.4 specifies the main drivers for the user requirements in Public Transport.
- Sub-section 5.5 drives the main conclusions from this section.

Finally, section 6 provides a detailed overview of the GNSS User Requirements Specifications in Public Transport per type of platform and application.

02 EXECUTIVE SUMMARY

2.1 KEY TRENDS AND MARKET EVOLUTION

The market for GNSS in the Public Transport domain has been experiencing continuous growth over the past years. GNSS is being used by public transport operators in various ways, starting from more efficient fleet management and vehicle availability to accurate passenger information and on-demand transport. Furthermore, GNSS-based solutions can also allow for a further development of green transport by serving as a base for shared mobility, such as shared vehicles, free-floating bikes, among others.

While the current use of GNSS in Public Transport is relatively limited when compared to other, more developed sectors, statistics show that there is still an important existing user base of GNSS: 62% of respondents to a survey on GNSS awareness[1] stated already using GNSS in their day-to-day activities, while 91% said that they believed that this technology could bring significant benefits to their work and improve urban mobility. This is supported also by an increasing number of public transport operators that have been adhering to the use of Galileo-based applications in their day-to-day operations in the last couple of years[2]. This growing trend to use GNSS-based solutions is not limited to public transport as we know it, but also reflected in the ever-growing Mobility-as-a-Service solutions.

When it comes to the main market players, they are to a large extent the well-established companies in the GNSS and automotive industry, which manufacture GNSS components and receivers, as well as the rolling stock. However, on the user side, the panorama is slightly different, with the public transport operators and authorities being among the key decision and strategy-makers, influencing the behaviour of the remaining players along the value chain based on the user requirements for Public Transport.

2.2 PERSPECTIVE USE OF GNSS IN PUBLIC TRANSPORT

As mentioned above, GNSS has been increasingly used in Public Transport across multiple applications and in two main categories (i.e. smart mobility and safety critical applications), as summarised in the table below.

	Bus	Tram	Rail
SMART MOBILITY	• Bus ITS: Fleet Management • Bus ITS: Passenger Information • Bus driver advisory systems • In-vehicle signage • Traffic signal prioritisation	• Tram ITS: Fleet Management • Tram ITS: Passenger information • Tram energy charging • Tram track lubrication	• Rail ITS: Fleet Management • Rail ITS: Passenger information • Train energy charging
CRITICAL APPLICATIONS	• Driving monitoring • Emergency electronic break • Cooperative intersection or other cooperative ITS • Autonomous shuttle	• Emergency electronic break • Tram level crossing protection • Tram door control supervision	• Train door control supervision • Train level crossing protection

1 http://ariadna-project.eu/wp-content/uploads/2021/01/ARIADNA-_-takeaways-survey.pdf
2 See for example the Madrid Municipal Transport Company or the Prague Public Transport Company.

However, the applications of GNSS to Public Transport are not limited to the existing ones exposed in the table, with new applications being continuously developed and tested. Here, there are several others that stand out as the most promising future applications, namely:

- Micro-mobility applications such as ride-, car-, bike-, and scooter-sharing that use GNSS-enabled smartphone applications to the organisation of supply and demand;
- Autonomous shuttles, that have been driving in testing mode across a number of European cities and where GNSS is one of the key sensors used for the positioning, navigation and timing;
- And Mobility-as-a-Service applications, that have been integrated into the public transport system in a number of cities across Europe and for which GNSS is also one of the crucial elements to ensure their correct and reliable functioning.

2.3 DRIVERS FOR USERS' REQUIREMENT AND E-GNSS PROPOSITION

Considering the context in which the public transport operates nowadays, which is increasingly demanding, and the applications that appear as most relevant, the following elements driving the user requirements in terms of EGNSS have been identified:

- Authentication and robustness
- Cost effectiveness of solutions
- High accuracy and availability in urban environments
- Ability to scale-up the solution
- Ability to integrate intermodality in the solution
- Development of V2X applications
- Cybersecurity

2.4 CONCLUSION

Given all of the above, one can observe growing needs for efficient public transport and the subsequent stricter and more demanding requirements in terms of performance of GNSS-based solutions. Within this context, Galileo offers real advantages and has a major role to play. If multi-constellation, multi-frequencies receivers will be able to improve the positioning in urban environment, the most demanding applications like collision avoidance, lane keeping, and automatic braking will require authentication, integrity and robustness.

The enrichment of applications concerns on the one hand smart mobility applications, such as passenger information and fleet management. But GNSS now also encompasses safety critical applications such as emergency breaking for trams or door control supervision for trains thanks to dedicated EGNSS signals and specific services (OS NMA, HA).

Beyond the modernization of fleets, the actual users of a wide range of mobility solutions will also benefit of the global localization services provided by Galileo, such as an improvement of the detection of pedestrians on crossroads.

03 REFERENCE DOCUMENTS

Ref.	Reference	Title	Date
	UCP session on Public Transport	Public Transport session – Update of User Requirements	December 2020
	New GNSS paradigms in Road	Technical analysis of new paradigms increasing EGNSS accuracy and robustness in vehicles	May 2015
	Previous project on Public Transport	Provision of specialised support to GSA's market development in the area of urban public transport GSA/OP/09/16/Lot 3/SC1	January 2019
	Ariadna Project Survey	How satellite navigation is empowering Public Transport & Urban Mobility solutions?	2020
	Shared mobility market overview	Global Shared Mobility Market Size & Trends Will Reach to USD 238.03 billion by 2026: Facts & Factors	December 2020
	Smart Cities Marketplace	Why Cities Should Prepare a Shared Mobility Plan for the Future	September 2017
	Monitor Deloitte	Car sharing in Europe. Business Models, National Variations and Upcoming Disruptions	2017
	Robotics Business Review article	Moving the Masses: Autonomous Vehicles in Public Transport	March 2018
	Driverless Buses article	5 Cities With Driverless Public Buses On The Streets Right Now	October 2015
	Navya autonomous shuttle	Self-Driving Shuttle for Passenger Transportation	n.a.
	Autonomous shuttle in Lisbon article	When autonomous transport meets the Lisbon MOBI SUMMIT	September 2019
	European Mobility Week	Pilot with autonomous shuttle bus	August 2018
	Autonomous shuttles in Vienna	In 2019 self-driving shuttles will hit the streets in Vienna	April 2018
	FABULOS Project	FABULOS Project	n.a.
	Ommelander Hospital Scheemda	Ommelander Hospital Scheemda	2018
	Autonomous shuttle in Paris	Autonomous shuttles tested in Paris La Défense	April 2019
	MaaS4EU Project	MaaS4EU Project	n.a.
	MaaS Alliance	What is MaaS?	n.a.
	International Transport Forum	New Shared Mobility Study on Helsinki Confirms Ground-breaking Lisbon Results	October 2017
	MaaS Alliance	MaaS in Action	n.a.
	Touring MaaS	Final report Mobility as a Service from Touring: complementary to private car	November 2017
	Reach Now	Our multimodal solution Reach Now	n.a.
	Techno. Report	GNSS Technology Report issue 1	2016
	Transdev digital solutions	Applications and digital solutions	n.a.
	EIP-SCC	New Mobility Services	n.a.
	Whim app	Whim app	n.a.

04 GNSS MARKET OVERVIEW AND TRENDS FOR PUBLIC TRANSPORT

4.1 MARKET EVOLUTION AND KEY TRENDS

Public transport is one of the domains in which the use of GNSS is currently in a rapid development phase. Not only the traditional public transport modes (i.e. bus, tram or light rail) are increasingly using GNSS-based solutions, but also the more innovative and alternative urban transport modes, such as shared mobility solutions, are increasingly relying on continuous and accurate positioning, navigation and timing (PNT) information.

GNSS can support public transport operators in various ways, starting from more efficient fleet management and vehicle availability to accurate passenger information and on-demand transport. Furthermore, GNSS-based solutions can also allow for a further development of green transport by serving as a base for shared mobility, such as shared vehicles, free-floating bikes, among others.

Public transport is one of the domains in which the use of GNSS is currently in a rapid development phase

Looking more in-depth to the use of GNSS in traditional public transport modes, a survey, targeting 70 entities organising the public transport in in the EU and beyond, launched in the frame of the ARIADNA project[3], found that 62% of its respondents use satellite navigation to plan or operate their services and over 91% of the respondents agree that the use of GNSS-based solutions can greatly improve the urban mobility. Given the increasing interest in and awareness about the possibilities that GNSS can bring to the public transport systems, it is expected that the share of transport operators using GNSS in their activities, which now stands at around 62%, will further increase in the upcoming years.

In terms of applications, and focussing on Europe, over the past years has been observed a growing trend to include GNSS-based solutions in the public transport. The most popular applications of GNSS to traditional public transport are the fleet and traffic management systems, as well as real-time passenger information system. The traffic signal prioritisation and smart ticketing are some other applications that have been widely explored by the transport operators in the EU, which have shown a wide interest in such systems[4].

When it comes to the shared mobility, this is a sector that has by itself experienced a steep growth in the past years. Furthermore, the shared mobility solutions (e.g. shared or free-floating bikes, shared cars and scooters, dynamic ridesharing, etc.) by themselves are typically highly digitalised and require positioning information for their correct functioning. According to some publications[5], the global shared mobility market was estimated at about 99 billion EUR in 2019 and expected to grow at about 15.4% annually between 2019 and 2026. This number is smaller in Europe, standing at about 5 billion EUR in 2017[6]. Despite of a relatively low shared mobility market in Europe, this sector is experiencing a steep growth of about 20% yearly[7], with new shared vehicles appearing in the European cities almost daily and representing growing opportunities for GNSS.

3 http://ariadna-project.eu/wp-content/uploads/2021/01/ARIADNA-_-takeaways-survey.pdf
4 Based on a previous study developed by VVA
5 https://www.globenewswire.com/news-release/2020/12/10/2143121/0/en/Global-Shared-Mobility-Market-Size-Trends-Will-Reach-to-USD-238-03-billion-by-2026-Facts-Factors.html#:~:text=According%20to%20the%20research%20study,15.42%25%20from%202019%20to%202026.
6 https://smart-cities-marketplace.ec.europa.eu/news/why-cities-should-prepare-shared-mobility-plan-future
7 https://www2.deloitte.com/content/dam/Deloitte/de/Documents/consumer-industrial-products/CIP-Automotive-Car-Sharing-in-Europe.pdf

4.2 MAIN MARKET PLAYERS

Figure 2: GNSS value chain for public transport

Users

TRADITIONAL PUBLIC TRANSPORT
- Public transport authorities
- Public transport operators
- Municipalities

SHARED MOBILITY
- Shared mobility providers

Component manufacturers

- HIRSCHMAN
- FURUNO
- JAPAN RADIO CO
- INFINEON
- KATHREIN
- NXP SEMICONDUCTORS
- MICRON
- ON SEMICONDUCTOR
- SK HYNIX
- ST MICROELECTRONICS
- U-BLOX

Tier 1 suppliers

- ACTIA
- BCE – BALTIC CAR EQUIPMENT
- EUROTECH
- FICOSA
- GMV
- NAVCOM TECHNOLOGY
- PCTEL
- PULSE LARSEN
- STONERIDGE

OEMs

- ALSTOM
- BMW
- BOMBARDIER
- CAF
- FIAT
- HITACHI
- IVECO
- MAN
- MERCEDES-BENZ
- NEWAG GROUP
- PESA
- PEUGEOT-CITROEN RENAULT
- SCANIA
- SIEMENS
- SOLARIS
- VAN HOOL
- VOLKSWAGEN
- VOLVO

When it comes to the main market players, the public transport value chain as it is addressed in this study needs to be split in two: on the one hand a value chain relative to the traditional public transport mentioned above, and on the other hand, the more innovative shared mobility. These two value chains operate in parallel, address a very similar market and have several points in common as can be observed on the figures above.

Thus, the figure above represents the **value chain of the traditional and the innovative public transport in Europe.**

As represented on the figure above, **the users of GNSS solutions for public transport are the first component in the value chain**, as those are the entities that identify the needs in terms of navigation technologies for public transport, often stand at the top of the decision making and also provide the transport services. This is particularly true for the traditional public transport, where the **public transport authorities** and **municipalities** have the role of identifying, together with the transport operators, the passenger needs, and issuing regulation on the minimum requirements to be fulfilled and technology to

be used by public transport operators[8]. In this way the public transport authorities drive the use of technologies, including GNSS, in buses, trams, light rail, etc. The urban public transport authorities are typically operating at the city level and responsible for the totality of public transport modes in their city.

The **public transport operators**, by their turn, are companies, in some cases private contractors to the authorities and in others publicly owned companies, that are responsible for the provision of the public transport services to the passengers. They typically own their own bus/tram/light rail fleet and are responsible for ensuring the availability and functioning of the public transport in their domain, all while answering to the needs and regulations traced by the authorities, as well as the user needs. They are also the ones that will procure the technologies necessary to satisfy the user and authority requirements, including when it comes to PNT solutions.

In the case of the **innovative urban mobility solutions**, this is a differently structured segment, focussing on the transport needs of individual passengers, rather than on the requirements of public transport authorities. They are typically not part of the public transport procurements schemes and operate on market-driven basis, being the ones deciding on the technologies and PNT solutions that they recur to. This segment of the value chain has been experiencing a continuous and steep growth in the recent years with an increasing offer of various shared mobility solutions (e.g. shared vehicles, shared bikes, shared scooters, etc.).

When it comes to the **supply side of the value chain**, it is composed by a few main actors, as described below[9]:

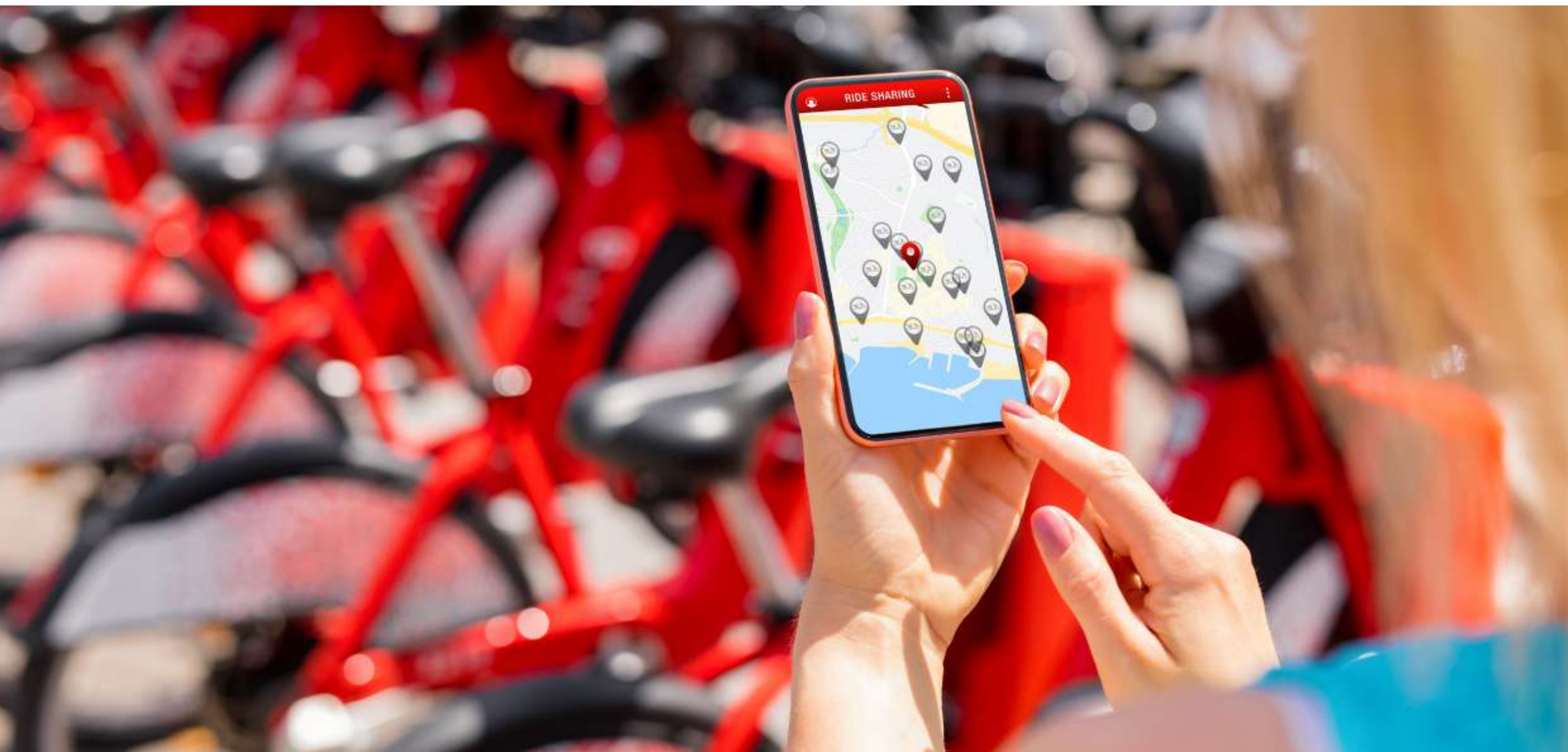
- The **component manufacturers** are the producers of the parts used by tier 1 suppliers for manufacturing of receivers and other GNSS-related products. This category of suppliers is mainly constituted by well-established players on the market.
- The **Tier 1 suppliers**, as briefly mentioned above, produce GNSS receivers and other GNSS-related products, which they supply to the vehicle manufacturers to be integrated into the vehicles (i.e. buses, trams, bikes, shared cars, etc.).
- The **OEMs**, by their turn, produce the rolling stock and integrate the parts suppliers by Tier 1 category into their vehicles. These vehicles are then supplied either to the transport operators in the case of the traditional public transport, or to the shared mobility providers in the case of the innovative/alternative urban mobility solutions.

4.3 MAIN USER GROUPS

The target groups that are key to facilitate the development and increased use of the GNSS in urban public transport are as follows:

- **Group 1:** Public transport authorities. As explained in section 4.2, the public transport authorities are the entities usually responsible for identifying the user requirements in terms of public transport in general, and in terms of PNT information in specific, and translating them into conditions/requirements within the

[8] Based on a previous study developed by VVA
[9] Based on a previous study developed by VVA



> The end user community have a significant, although indirect, influence on the performance of the technologies used by public transport operators

procurement of public transport service providers. Thus, although the public transport authorities typically cannot decide on the specific technology to be used, they do have the responsibility to frame the user needs, which then will be addressed by the operators by means of certain technologies.

- **Group 2:** End users. As explained above, the requirements established by the public transport authorities towards the operators when procuring public transport services are largely defined by the needs expressed by the public transport users. A similar situation is observed in the field of innovative mobility solutions, such as shared mobility: being it market-driven, the end users influence directly the developments in terms of shared mobility offers and the service providers constantly search for better ways to provide the service that would satisfy the user requirements. In this sense, the end user community (i.e. the passengers o public transport) have a significant, although indirect, influence on the performance of the technologies used by public transport operators and other service providers (e.g. shared mobility providers).
- **Group 3:** The industry. This group is a highly important one, since they possess a significant technical and technological knowledge in terms of GNSS. They also are the ones that will be developing the technologies and solutions that will be included by the OEMs in their rolling stock and that will, ultimately, respond to the user requirements identified and framed by the authorities or demanded by the market. The Tier 1 suppliers constitute a particularly critical group as they are the ones developing the GNSS equipment itself. Furthermore, they act as a link between the component manufacturers and the OEMs in the development of GNSS equipment.
- **Group 4:** Standardisation bodies. Similarly to what happens in Road sector, the standardisation bodies that are well-aware of the benefits of GNSS in terms of performance, but also in terms of benefits that it can bring to the public transport (e.g. safety, punctuality, etc.), can play an important role when defining the technology to be used to satisfy certain user requirements.
- **Group 5:** Research institutions. The research institutions working in the field of satellite navigation and transportation are an important reference when it comes to showcasing the benefits and performance of certain technology (e.g. GNSS). By being able to scientifically showcase the benefits and performance of GNSS in public transport-related fields, this group can have a significant influence on further incorporation of GNSS into the public transport and shared mobility.

05 GNSS USER REQUIREMENTS ANALYSIS

5.1 GNSS USE IN PUBLIC TRANSPORT

5.1.1 Main GNSS techniques used in public transport applications

Nowadays GNSS is widely used in Public Transport across multiple usages: Advanced Driver Assistance System (ADAS) services, cooperative Intelligent Transport System (ITS), autonomous driving and more globally Mobility as a Service solutions are emerging to answer the increasing need of mobility of citizens. The positioning and timing information provided are entering in a new era: accuracy, reliability, authenticity, integrity will have to reach higher level of performance.

Due to natural constraints in tunnels, in towns or under dense canopy where GNSS signals are obstructed, or strongly distorted manufacturers use various hybridization technics. Hybridization is normally performed to meet the requirements of the different applications and consists in coupling the GNSS information with other on-board sensors like accelerometer, odometer and gyroscope.

The solution deployed depends on the type of platform operated, but currently most of the public transport platforms using GNSS are relying on the use of GPS L1 signals to provide information to the IVS. As new needs emerge future solution will lead to increased performance requirements, opening the way to more advanced GNSS solutions such as the ones provided by multi-constellation multifrequency receivers.

5.1.2 Overview of Public Transport Applications

The different Public Transport applications are divided into two categories: smart mobility and safety critical applications.

The identified smart mobility applications are the following:

- **Coordination of public transport fleets:** public transport providers manage several transport modes such as busses, trains and trams through their fleet management systems.
- **Provision of passenger information:** public transport users' frictions with the transit system can arise on all the existing transport modes. A general information streaming encompassing all the existing transport modes is required to support users in their public transport use.
- **Scheduling and optimisation of passenger travel:** bus drivers are supported by advisory and traffic signals prioritisations systems. Those systems help drivers to adopt a smooth and optimised travel for their passengers. In addition, the bus, train and trams travels are optimised and scheduled thanks to fleet management systems.
- **React to real time information:** fleet management systems, driver advisory systems and in vehicle signage allow buses, trams and trains to react in real time to the public transit incidents or traffic jams.
- **Gas emissions reduction:** optimising the buses and electric cars travels duration and length contributes to reduce gas emissions as well as to reduce the public transit system operation cost for the public transport operators.
- **Respond to new Public Transport demands:** demand-based mobility applications aim at offering specific pick up and drop off services to passengers and are based on the use of buses fleets.

The identified safety critical applications are the following:

- **Driving aids for the buses, trams or trains drivers:** the safety critical applications aim at supporting buses, trains and trams drivers in the adoption of a safe driving by providing them with safety related information about their complex environment.
- **Ensuring safety of public transport passengers:** the received safety related information contribute to the improvement of the buses, trains and trams passengers' safety. In addition, the door control supervision systems use the trains or trams position information to identify the station and determine how many doors shall be opened and on what side of the train.

- **Autonomous driving of buses (including shuttles):** This particular safety critical application is increasingly becoming a reality for buses platforms and appears to have more stringent requirements as there are no human drivers behind the wheel.
- **Rail maintenance:** the trains and trams position information is combined with a speed and lateral acceleration sensors to report potential track, switches and catenaries damages and need for maintenance.

The table hereafter summarizes the different applications corresponding to the above-listed tasks for each platform.

Table 1: Overview of Public Transport applications

	Bus	Tram	Rail
SMART MOBILITY	• Bus ITS: Fleet Management • Bus ITS: Passenger Information • Bus driver advisory systems • In-vehicle signage • Traffic signal prioritisation	• Tram ITS: Fleet Management • Tram ITS: Passenger information • Tram energy charging • Tram track lubrication	• Rail ITS: Fleet Management • Rail ITS: Passenger information • Train energy charging
CRITICAL APPLICATIONS	• Driving monitoring • Emergency electronic break • Cooperative intersection or other cooperative ITS • Autonomous shuttle	• Emergency electronic break • Tram level crossing protection • Tram door control supervision	• Train door control supervision • Train level crossing protection

5.1.3 Existing and coming EU regulations

Different regulations are applicable depending on the platform considered.

ROAD REGULATION

For the road segment covering the buses several existing EU regulations are driving the use of GNSS:

- Delegated regulation 886/2013 for the provision of road safety related minimum universal traffic information follow up of directive 2010/40/EU
- Delegated regulation 962/2015 supplementing Directive 2010/40/EU with regard to the provision of EU wide real time traffic information services
- Regulation 165/2014 on tachographs in road transport
- Regulation 2015/758 and 2017/78 concerning type approval requirements for the deployment of eCall in vehicle systems follow up of Directive 2010/40/REU

5.1.4 Performance parameters

The table in ANNEX 2 identified and defines the technical requirements applicable to the public transport applications that are considered. For the purpose of consistency, the considered performance parameters were extracted from the UCP public transport session.

Over the past years, huge efforts have been made by the public transport communities to identify the requirements applicable to GNSS. For instance, the GNSS user requirements have been analysed and discussed during the last UCP organised in December 2020. The UCP documents contain the most recent User Requirements for multiple GNSS applications.

Most of the user requirements identified in this chapter have been extracted from UCP reports. Additional desk research and validation by experts of the public transport sector have been performed to complete the user requirements of the public transport.

IDENTIFICATION OF PUBLIC TRANSPORT USER TECHNICAL REQUIREMENTS

The following performances parameters are listed and described in Annex 2. A short description of each parameter is provided:

1. Horizontal position accuracy
2. Vertical position accuracy
3. GNSS time accuracy
4. Time to first fix
5. Position authenticity
6. Robustness to interference
7. Position integrity
8. GNSS sensitivity
9. Availability
10. Continuity

The performance features reported above describe the behavior of the positioning terminal when it operates in relationship and interaction with the external world. However, in addition to the performance features reported above, there are other two important parameters of the positioning terminal that are determined by the design of the terminal and can influence the overall service performance:

11. Position fix rate
12. Latency

The GNSS receiver remains the fundamental source of absolute positioning among the other sensors. In addition, most of the positioning performance features have been derived from a context in which positioning was essentially GNSS-based only. For applications such as safety critical ones, some of the requirements put on the positioning terminal directly pass to the GNSS receiver, while others must be appropriately shared with the other sensors.

5.1.5 Applications categories

A general description of each application is provided in the following sub-sections.

APPLICATIONS IDENTIFIED FOR BUSES

The table below provides a high-level overview of current applications that have been identified for the use within buses alongside a high-level description of the application.

SMART MOBILITY

Table 2: Overview of the smart mobility applications for buses

Application	Description
ITS: Fleet Management *(similar to fleet management for commercial vehicles)*	Aggregation of services/applications to optimize the transport system. This application provides a clear overview of all busses and where they are located throughout the city/bus routes.
ITS: Passenger Information *(similar to Rail passenger information, tailored for busses)*	Providing real-time information to the passengers concerning the transport location and the estimated time of arrival at designated bus stops.
Traffic Signal Prioritisation	The system provides public transportation with green lights in order to keep the operations/traffic smooth-running and according to the schedule.
Bus Driver Advisory Systems	Providing real-time information to the bus driver regarding the external and/or internal conditions of the vehicle to facilitate the decision-making regarding the optimal driving control of the vehicle.
In-vehicle signage	A static or dynamic sign information is displayed to the driver without roadside units, just taking into account the localization and direction of the vehicle on the road.

SAFETY CRITICAL

Table 3: Overview of the safety critical applications for buses

Application	Description
Driving monitoring	Analysis of the driving in order to evaluate the driver's safety and driving practices.
Emergency electronic break	In case of severe braking or blockage of the bus, an alert message with the vehicle's location is sent to coming vehicles.
Cooperative intersection or other cooperative IT	At intersections the system warns drivers about likely violations of traffic control devices and help them manoeuvre through cross traffic.
Autonomous shuttle	Autonomous shuttle is a vehicle capable of transporting passengers or logistics on private sites, urban, suburban or rural areas in diverse environments such as school campuses, residential communities, office parks, business districts and event spaces. It operates on predefined routes or geofenced locations such as corporate or university campuses, or last mile travel between transport hubs and final destinations. It combines a variety of techniques to perceive its environment including GNSS.

APPLICATIONS IDENTIFIED FOR TRAMS

The table below provides a high-level overview of current applications that have been identified for the use within trams alongside a high-level description of the application.

SMART MOBILITY

Table 4: Overview of the smart mobility applications for trams

Application	Description
ITS: Fleet Management *(similar to fleet management for commercial vehicles, but tailored to light rail)*	Aggregation of services/applications to optimize the transport system. This application provides a clear overview of all trams and where they are located throughout the city/tram lines.
ITS: Passenger Information *(similar to Rail passenger information, tailored for trams)*	Providing real-time information to the passengers concerning the transport location and the estimated time of arrival at designated tram stops and platforms.
Tram energy charging *(similar to Rail energy charging)*	To monitor the energy consumption of trams and their users, trams can be equipped with GNSS devices and energy meters.
Tram track lubrication	Use of GNSS for the efficient distribution of lubrication on the tram tracks (mainly on junctions and tight curves) that contributes to a reduction of noise and dustiness as well as contributes to a reduction of maintenance costs of the tracks and undercarriages of trams. Since these lubrication materials are both expensive and of potential environmental concern, accurate GNSS is necessary to optimise the lubrication process and mitigate negative externalities.

SAFETY CRITICAL

Table 5: Overview of the safety critical applications for trams

Application	Description
Emergency electronic break	In case of severe braking or blockage of the tram, an alert message with the vehicle's location is sent to coming vehicles.
Tram level crossing protection *(similar to Rail level crossing protection)*	The GNSS subsystem should manage a digital map with geographical information to optimize the traffic incl. level crossing location, track description in the level crossing surroundings, location activation/deactivation points, etc.
Tram door control supervision *(similar to Rail door control supervision)*	GNSS-assisted application to monitor the location of the tram vis-à-vis the location of tram platforms. Enables the opening of specific doors aligned with the platform (e.g. preventing doors to open when the platform is shorter than the tram).

APPLICATIONS IDENTIFIED FOR TRAINS

The table below provides an overview of current applications that have been identified for the use within trains alongside a high-level description of the application.

SMART MOBILITY

Table 6: Overview of the smart mobility applications for trains

Application	Description
Rail Fleet Management	Aggregation of services/applications to optimize the transport system. Tracking of all assets such as the wagons. Similar to Fleet Management of commercial vehicles (i.e. trucks), the applications also contribute to the management of maintenance of the rolling stock.
Rail Passenger Information	Providing real-time information to the passengers concerning the transport location and the estimated time of arrival at designated train stops and platforms.
Train Energy Charging	To monitor the energy consumption of trains and their users, trains can be equipped with GNSS devices and energy meters. Use of GNSS to locate the position of the train and to provide an accurate recording point for invoicing.

SAFETY CRITICAL

Table 7: Overview of the safety critical applications for trains

Application	Description
Train door Control Supervision	Train door control supervision GNSS-assisted application to monitor the location of the train vis-à-vis the location of train platforms. Enables the opening of specific doors aligned with the platform (e.g. preventing doors to open when the platform is shorter than the tram).
Train level crossing protection	The GNSS subsystem should manage a digital map with geographical information to optimize the traffic incl. level crossing location, track description in the level crossing surroundings, location activation/deactivation points, etc.

5.2 PROSPECTIVE USE OF GNSS IN PUBLIC TRANSPORT

When it comes to the future applications, two of them clearly take the lead in coverage across research papers, press articles and reports forecasting the future of urban public transport. These applications are:

- Autonomous shuttles;
- And Mobility-as-a-Service applications.

Besides these prospective applications, this section also provides an overview of some other non-traditional public transport applications that cannot be associated with either buses, trams or train. These so-called new mobility applications are associated with other platforms such as smartphones or vehicles such as bikes.

5.2.1 Autonomous shuttles

With around two dozen European cities experimenting autonomous shuttles on test-tracks, closed circuits and pilots on public roads, the future for autonomous shuttles looks bright[10]. Back in 2015[11], a hand-full of cities kicked off first tests with autonomous shuttles and this number has steadily gone up whilst the number of companies involved in the development in autonomous shuttles is on the rise.

> With around two dozen European cities experimenting autonomous shuttles, the future for autonomous shuttles looks bright

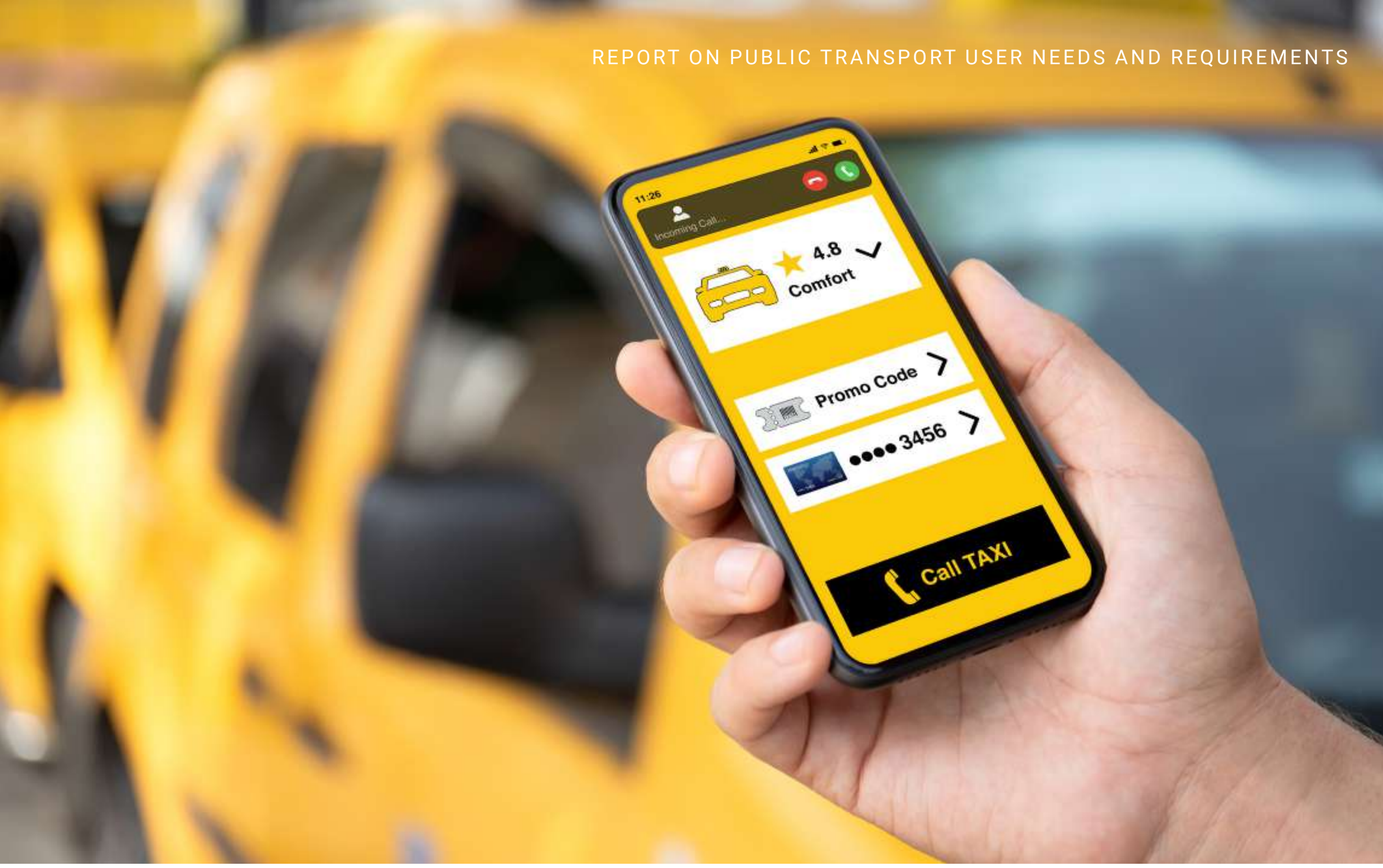
Among the European cities that have been serving as test beds for the autonomous shuttles one may find Paris, Lyon[12], Lisbon[13], Luxembourg[14], Scheemda[15], Vienna[16] and Brussels[17]. On top of this, there are projects on the way aiming to bring systematic autonomous public transportation solutions to the streets of an even bigger number of European cities[18]. The shuttles being tested have the capacity of approximately 10 to 15 passengers, are able to operate on short, well-defined routes and are free of charge due to the testing nature of this activity. According to some of the stakeholders interviewed, the earliest date previewed for the introduction of the first autonomous shuttle operational outside the test environment is 2021.

Amongst others, specialized companies such as 2GetThere, EasyMile, Local Motors, Navya, but also established manufacturers such as VDL Bus & Coach, or companies such as Siemens and Ericsson are all involved in the path towards the market deployment of autonomous shuttles for urban public transport services. These companies often engage in autonomous shuttle-related activity in partnership with transport operators, such as Transdev, Keolis or Arriva[19], or yet local or regional public companies, as is the case of De Lijn in Belgium. The tests are often organised in partnerships with public transport authorities in the corresponding cities, as is the case of the shuttle in La Defense quarter in Paris, for instance[20].

Despite of all the testing activity going on in the domain of autonomous shuttles, some challenges are yet to be overcome. Some of these challenges are of physical nature and consist mainly in complex weather conditions (i.e. heavy rain, fog or snow), which make the task of reading the environment correctly more difficult, as well as in a correct reading of the public infrastructure[21]. Another challenge identified is related to the regulatory aspect of autonomous vehicle testing. As referred by some of the stakeholders interviewed, when it comes to the testing of autonomous shuttles, or autonomous vehicles in general, there is a strong need for a regulatory framework on local, regional or national level, that allows and incentivises such activity[22].

---

10 2018 Robotics Review article – Moving the masses: Autonomous Vehicles in Public Transport
11 2015 Gizmodo article – 5 Cities with driverless public buses on the streets right now
12 Navya website
13 2018 Transdev article – When autonomous transport meets the Lisbon MOBI SUMMIT
14 2018 Navya article – Navya and Sales-Lentz unveil Luxembourg's first autonomous shuttles
15 2018 European Mobility Week publication – Pilot with autonomous shuttle bus
16 2018 Avenue 21 article – In 2019 self-driving shuttles will hit the streets in Vienna
17 2018 Brussels Airport publication – Brussels Airport and De Lijn start pilot project with self-driving bus
18 FABULOS project
19 https://www.autonoomvervoernoord.nl/projecten/ozg-scheemda/
20 2018 Île-de-France Mobilités publication - Des navettes autonomes expérimentées à Paris La Défense
21 2018 Keolis article – Keolis starts operating its first autonomous electric shuttle though its Belgian subsidiary
22 Source: stakeholder consultation



5.2.2 Mobility-as-a-Service

With the view to reduce the use of private cars as the main mode of transport in the cities and its underlying consequences such as traffic congestion and poor air quality, it is important to make collective and green mobility solutions increasingly appealing to the users. The role of Mobility-as-a-Service (MaaS) is to bring together all the available means of transport and provide to the end user a tailor-made travel solution, based on their needs and current conditions[23]. This service integrates not only the traditional public transport means, but also the innovative solutions, such as bike or car sharing, taxi, etc.[24] By doing so, MaaS is able to respond to the current shift in the consumers' needs towards transport on demand, reduced travel time and flexibility, which were pointed out by several stakeholders.

Several studies have been conducted, for instance in Lisbon and Helsinki, that confirm the benefits of MaaS when it comes to improving urban mobility, environment and quality of life, and freeing up urban space for other projects[25]. Currently, there is a number of cities across Europe that have been developing and introducing MaaS into their transport ecosystems. These cities include but are not limited to London, Paris, Amsterdam, Brussels, Lyon, Hamburg, Berlin and Lisbon[26].

Among active Mobility-as-a-Service providers in Europe one may find companies like Touring[27], Moovel Group[28] and MaaS Global[29], or else big and well-established market players such as Transdev[30]. These companies are working to deliver integrated mobility solutions that are accessible to large public and respond to the changing demand in an efficient way.

Finally, some challenges to the implementation of such system have been identified and need to be overcome. On one hand there is the complexity of a multi-stakeholder ecosystem, as it represents a somewhat new approach and may create obstacles on the way to achieve efficient interoperability and a sustainable business model. On the other hand, according to some studies, in bigger cities with a well-established public transport network the dependency on other modes of transport is relatively reduced, which makes it important to integrate the traditional public transport into the MaaS solution, in line with the innovative mobility methods[31]. In both

23 http://www.maas4eu.eu/
24 https://maas-alliance.eu/homepage/what-is-maas/
25 2017 ITF publication – New Shared Mobility Study on Helsinki Confirms Ground-breaking Lisbon Results
26 MaaS in action and stakeholder consultation
27 https://www.touring.be/nl/pers/eindrapport-mobility-service-van-touring-complementair-aan-priveauto
28 https://www.moovel-group.com/en
29 https://maas.global/
30 https://www.transdev.com/en/our-solutions/applications-and-digital-solutions/
31 EIP-SCC article – New Mobility Services

senses there are pilot projects ongoing with the view to develop a sustainable and demand-responsive Mobility-as-a-Service.

5.2.3 Applications across other platforms

The following table provides an overview of additional GNSS-enabled applications offering urban transport possibilities or integrated solutions, not specifically tailored to busses or trams. Across various cities in the European Union, these applications are being developed and deployed on a city-level, national level or cross-border level by global companies.

SMART MOBILITY

Table 8: Overview of the smart mobility applications for other platforms

Platform	Application	Description
Smartphone	Electro mobility	Applications allowing the optimising usage of Electric Vehicle (EV) while providing the best route, including charging spots as necessary.
Bike, scooter, car	Bike, scooter, car sharing	Combined with a corresponding smartphone application, providing the location of vehicles in self-service.
Car	Dynamic ride sharing	Similar to car sharing, but with the main emphasize to rely on the GNSS engine for the location and management of meeting points of individual users as well as to facilitate the fee calculations.

SAFETY CRITICAL

Table 9: Overview of the safety critical applications for other platforms

Platform	Application	Description
Smartphone	MaaS (smart ticketing)	This application offers travellers with electronic ticketing and payment services across all modes of transportation, public or private.
Car	Positive toll	When motorists agree not to use their vehicle during peak hours, they receive in return money. This application integrates the localization of the vehicle.

5.3 GNSS LIMITATIONS FOR PUBLIC TRANSPORT

Based on these GNSS open services characteristics and on the identified public transport users' requirements; the following limitations can be listed for the identified categories of public transport applications.

Table 10: GNSS limitations for Public Transport (Open Service)

	Current GNSS Limitations
Smart mobility	• No indoor penetration • Low robustness against interference • Low Robustness against spoofing • TTFF (Bus applications)
Safety critical	• No indoor penetration • No integrity • Low robustness against interference • Low Robustness against spoofing • TTFF (Bus applications) • No sub-meter accuracy (Bus applications) • Position fix rate (Bus applications)
Payment critical	• No indoor penetration • Low Robustness against spoofing • No integrity (except for Trains and Trams Applications) • Low robustness against interference (except for Trains and Trams Applications) • TTFF (except for Trains and Trams Applications)

Public transport applications users' requirements have highlighted several limitations for a sole use of GNSS services. Indeed, the GNSS position accuracy remains limited for the Safety critical applications that are installed on a bus or an autonomous shuttle platform. Indoor environments are challenging for GNSS signals propagation (e.g. inside tunnels, metro lines and stations) and the reduced availability in urban canyon environments appears to be one of the main limitations for an optimal use of GNSS open services in the public transport domain. The GNSS open services Time to First Fix (TTFF) performance is also perceived as a limitation by the public transport applications users that usually require a first fix in less than 30s for their operations.

Concerning the security aspects, the low level of robustness against interferences and spoofing is also expected to be a limitation for the public transport applications. Finally, the absence of integrity is a limitation for the safety critical, payment and regulation critical public transport applications that require confidence in the information provided by their GNSS receiver.

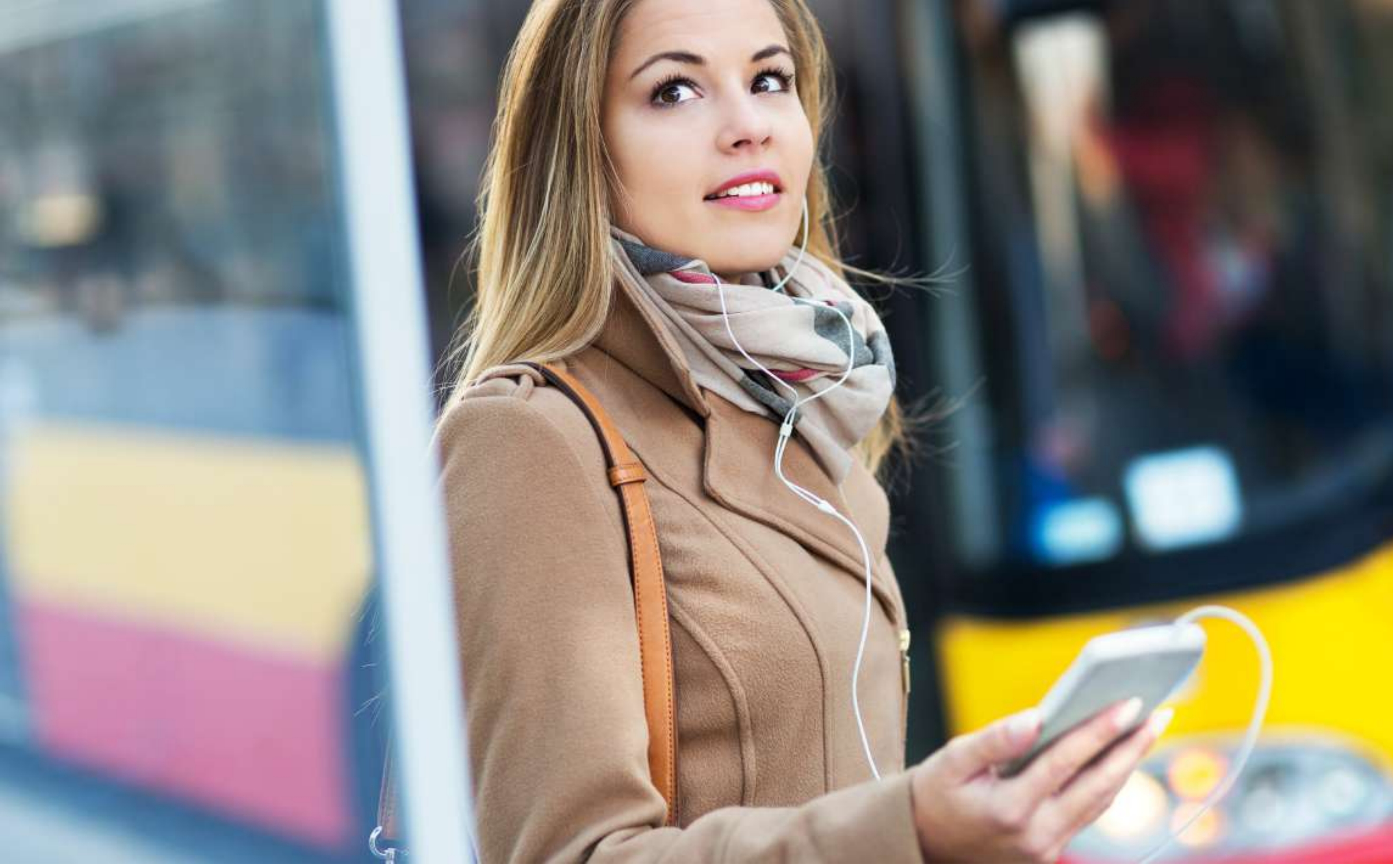
Therefore, if GNSS open services adoption is common within public transport applications and bring many added values, several limitations still exist that hinder a higher penetration of GNSS in Public Transport. To mitigate GNSS limitations, other technologies can be used either as complementary or substitute. New services could also mitigate those limitations, for instance the OS NMA currently under test could be an adequate solution for critical applications requiring authentication and robustness while the High Accuracy service would be more appropriate for applications such as the autonomous shuttle.

5.4 DRIVERS FOR USER REQUIREMENTS IN PUBLIC TRANSPORT

5.4.1 GNSS Open Services Usage in Public Transport

Several drivers have been identified for User Requirements in Public Transport; they are listed below.

- **Authentication and robustness** are becoming key parameters to mitigate the risks in all critical applications. Features linked to a payment such as scooter sharing for instance, are increasingly popular among users.
- **Cost effectiveness of solutions:** the spread of GNSS technology is also possible thanks to the limited cost of receivers compared to substitute technologies
- **High accuracy and availability in urban environments:** some applications such as the autonomous shuttle require high level of accuracy and availability to operate.
- **Ability to scale up the solution:** a real differentiator of GNSS technology compare to potential substitutes is the low cost to thanks to the limited infrastructure needed to deploy the solution. This is part of the value proposition of GNSS.
- **Ability to integrate intermodality in the solution:** users expressed the need of more continuous solutions not depending on the mode of transport at the latest UCP#3.
- **Development of V2X applications** will widen GNSS use, Vehicle to Everything (V2X) are not only related to cars but also to the “other” road users: motorcycles, cyclists, road workers etc., which could use GNSS to be localized as road user.
- **Cybersecurity:** is critical for GNSS solutions given the data managed. For instance, a security breach on the GNSS receiver for complex applications such as the autonomous shuttle could have severe consequences.



5.5 CONCLUSIONS

The use of GNSS in Public Transport is undergoing profound changes with the emergence of Galileo and the associated new services. From the legacy receiver relying on single frequency GPS signal, operators are now choosing and developing more sophisticated solutions to answer the requirements of the growing number of applications.

> The use of GNSS in Public Transport is undergoing profound changes with the emergence of Galileo and the associated new services

It is the case of the Prague Public Transit Company (DPP) that recently chose to modernize its GNSS receivers on the tram fleet to increase network efficiency and improve user experience. To reach new performance levels, they abandoned their 20 years old GPS only receivers for Galileo-enabled, multifrequency, multi-constellation receivers on their 838 trams. The consequences in terms of performance were direct: localization accuracy has been improved to 1.5 meters and the technology also offers new applications for passengers such as real-time data about departures.

In this context of growing needs for efficient public transports, Galileo offers real advantages and has a major role to play. If multi-constellation, multi-frequencies receivers will be able to improve the positioning in urban environment, the most demanding applications like collision avoidance, lane keeping, and automatic braking will need authentication, integrity and robustness.

The enrichment of applications concerns on the one side smart mobility applications such as passenger information and fleet management. But GNSS now also encompasses safety critical applications such as emergency breaking for trams or door control supervision for trains thanks to dedicated EGNSS signals and specific services (OS NMA, HA).

Beyond the modernization of fleets, the actual users of a wide range of mobility solutions will also benefit of the Global localization services provided by Galileo, like for instance improving the detection of pedestrians in crossroads.

06 USER REQUIREMENTS SPECIFICATION

6.1 SYNTHESIS OF UR ANALYSIS

The requirements have been gathered per platform and validated at the latest UCP in December 2020.

6.1.1 Requirements for Buses

REQUIREMENTS FOR SAFETY CRITICAL APPLICATIONS

Table 11: Requirements for bus safety critical applications

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0010	The positioning system shall provide an availability better than 99,9 %	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study “GSA/OP/09/16/Lot 3/SC1”
GSA-MKD-USR-REQ-PUB-0020	The positioning system shall be able to provide a fix rate accuracy within a range of 1-10 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study “GSA/OP/09/16/Lot 3/SC1”
GSA-MKD-USR-REQ-PUB-0030	The positioning system shall provide a horizontal accuracy better than 1 meter	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study “GSA/OP/09/16/Lot 3/SC1”
GSA-MKD-USR-REQ-PUB-0040	The positioning system shall provide a vertical accuracy better than 10 meters	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study “GSA/OP/09/16/Lot 3/SC1”
GSA-MKD-USR-REQ-PUB-0050	The timing system shall provide an accuracy within range of 1us –1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study “GSA/OP/09/16/Lot 3/SC1”
GSA-MKD-USR-REQ-PUB-0060	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Medium-High	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study “GSA/OP/09/16/Lot 3/SC1”

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0070	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

REQUIREMENTS FOR SMART MOBILITY APPLICATIONS

Table 12: Requirements for bus Smart Mobility

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0080	The positioning system shall provide an availability within a range of 95-99,9%	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0090	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0100	The positioning system shall provide a horizontal accuracy within a range of 1-10 meters	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0040	The positioning system shall provide a vertical accuracy better than 10 meters	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0110	The timing system shall provide an accuracy of 1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0120	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0130	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

6.1.2 Requirements for Trams

REQUIREMENTS FOR SAFETY CRITICAL APPLICATIONS

Table 13: Requirements for tram safety critical applications

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0140	The availability of the location information provided by the positioning system shall be High	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0090	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0030	The positioning system shall provide a horizontal accuracy better than 1 meter	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0110	The timing system shall provide an accuracy of 1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0150	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0130	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

REQUIREMENTS FOR SMART MOBILITY APPLICATIONS

Table 14: Requirements for tram Smart Mobility

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0160	The availability of the location information provided by the positioning system shall be Medium	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0090	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0170	The positioning system shall provide a horizontal accuracy within a range of 10-100 meters.	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0110	The timing system shall provide an accuracy of 1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0120	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0180	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be greater than 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

6.1.3 Requirements for Trains

REQUIREMENTS FOR SAFETY CRITICAL APPLICATIONS

Table 15: Requirements for train safety critical applications

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0140	The availability of the location information provided by the positioning system shall be High	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0090	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0030	The positioning system shall provide a horizontal accuracy better than 1 meter	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0110	The timing system shall provide an accuracy of 1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0150	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0130	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

REQUIREMENTS FOR SMART MOBILITY APPLICATIONS

Table 16: Requirements for train Smart Mobility

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0160	The availability of the location information provided by the positioning system shall be Medium	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0090	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0170	The positioning system shall provide a horizontal accuracy within a range of 10-100 meters.	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0110	The timing system shall provide an accuracy of 1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0120	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0180	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be greater than 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

6.1.4 Requirements for Other platforms

Considered as part of the new mobility applications, the tables below provide an initial overview of the user requirements for public transport applications that are associated with non-traditional means of public transport, such as:

- Electro mobility;
- Sharing platforms (e.g. bikes, scooters, cars, …);
- Dynamic ride sharing;
- Mobility-as-a-Service – Smart ticketing;
- Positive toll.

REQUIREMENTS FOR SAFETY CRITICAL APPLICATIONS

Table 17: Requirements for other platforms safety critical applications

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0160	The availability of the location information provided by the positioning system shall be Medium	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0090	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0100	The positioning system shall provide a horizontal accuracy within a range of 1-10 meters	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0040	The positioning system shall provide a vertical accuracy better than 10 meters	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0110	The timing system shall provide an accuracy of 1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0190	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Medium	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0180	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be greater than 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

REQUIREMENTS FOR SMART MOBILITY APPLICATIONS

Table 18: Requirements for other platforms Smart Mobility

id	Description	Type	Source
GSA-MKD-USR-REQ-PUB-0160	The availability of the location information provided by the positioning system shall be Medium	Performance (availability)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0090	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0100	The positioning system shall provide a horizontal accuracy within a range of 1-10 meters	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0040	The positioning system shall provide a vertical accuracy better than 10 meters	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0110	The timing system shall provide an accuracy of 1s	Performance (accuracy)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0190	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Medium	Performance (integrity)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"
GSA-MKD-USR-REQ-PUB-0180	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be greater than 30s.	Performance (Time To Alert)	[RD1] Validated at UCP 2020 [RD3] Identified under the 2019 study "GSA/OP/09/16/Lot 3/SC1"

07 ANNEXES

ANNEX 1: KEY STANDARDIZATION BODIES AND ORGANIZATIONS

The following list gathers the most relevant standardization bodies and working groups in the field of GNSS positioning that can influence R&D activities in GNSS performances, in particular for safety-critical applications:

ETSI TC SES/SCN

- Standards about GNSS performance, relevant for Location Based Services (land applications); focus on lab tests with simulators.
- Activities concluded, suite of 5 documents published related to "GNSS based location systems' (i.e. from TS 103 246-1 to TS 103 246-5).

CEN/CENELEC

- Standards about GNSS performance, relevant for road applications; focus on field tests, record & replay tests.
- Suite of 3 standard documents: EN 16803-1 (basic metrics), EN 16803-2 (field and "Record and Replay" testing procedures), EN 16803-3 (focus on spoofing and interferences).
- EN 16803-1 published in October 2016. On-going work (just started) for EN 16803-2 and EN 16803-3.
- Review of preliminary results preliminary results from the GP-START project (GNSS Performance Standardization for Road Transport).

OTHER RELEVANT WORKING GROUPS:

- **International Association of Geodesy (IAG):** Commission 4 – Positioning and Applications: WG 4.1.4 (Robust Positioning for Urban Traffic): Specification and characterization of GNSS requirements, performance analysis for vehicles and pedestrians in urban areas, etc.
- **ISO TC204 - Intelligent transport systems:** New project titled "TS 21176 - Intelligent Transport Systems – Cooperative ITS – Position, Velocity and Time functionality in the ITS station". Collaboration between ISO TC204/WG18 (Cooperative systems) and CEN TC5/WG1
- **ISO 26262 Road Vehicles-Functional safety:** functional safety of electrical and/or electronic systems in production automobiles defined by the ISO in 2011.
- **ISO 5725 accuracy of measurements:** accuracy (trueness and precision) of measurements methods and results, to establish practical estimations of the

various measurements. European Road Transport Research Advisory Council (ERTRAC): European Technology Platform (ETP) for Road Transport, recognized and supported by the European Commission. Even if ERTRAC is not a standardization organization, it has the relevant role to provide a strategic vision for road transport research and innovation; define strategies; stimulate effective public and private investment in road transport research and innovation.

- **Open AutoDrive Forum (OADF):** it is an initiative to harmonize the activities from NDS, TISA, ADASIS and SENSORIS created in 2015. The overarching objective is to generate an ecosystem of production-ready automotive standards including navigation and positioning.
- **European Transport Safety Council (ETSC):** Independent expert advice on transport safety matters to the European Commission, the European Parliament, and Member States. Recommendation document: "Prioritising the Safety Potential of Automated Driving in Europe", 2016.
- **Cloud Large Scale Video Analysis (LSVA) project – Open Group:** Focus on navigation data, maps, and support the development of suitable standards for video data set and video annotation, aim at developing a standard on video content annotation to be published by an existing appropriate SDO.
- **Society of Automotive Engineers (SAE) International:** On-Road Automated Driving (ORAD) committee. Documents released:
  - J3016 Taxonomy and Definitions for Terms Related to On- Road Motor Vehicle Automated Driving Systems: Definition of well-known levels of automation.
  - J3018 Guidelines for Safe On-Road Testing of SAE Level 3, 4, and 5 Prototype Automated Driving Systems (ADS).
  - J3092 Dynamic Test Procedures for Verification & Validation of Automated Driving Systems (ADS) - Work in progress.
  - J3131 Automated Driving Reference Architecture - Work in progress.

ANNEX 2: DEFINITION OF KEY GNSS PERFORMANCE PARAMETERS

This Annex provides a definition of the most commonly used GNSS performance parameters, coming from [RD23] and including additional details which are relevant for the Public Transport community.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%. There are two classes of availability:

- **System**: the percentage of time the system allows the user to compute a position – this is what GNSS Interface Control Documents (ICDs) refer to.
- **Overall:** takes into account the receiver performance and the user's environment (for example if they are subject to shadowing).

Availability is one of the most important performance features in supporting any safety-critical application, e.g. emergency services.

Availability is one of the most important performance features in supporting any safety-critical application, e.g. emergency services.

Accuracy: the difference between true and computed position (absolute positioning). This is expressed as the value within which a specified proportion of samples would fall if measured. Typical values for accuracy range from tens of meters to centimeters for 95% of samples. Accuracy is typically stated as 2D (horizontal), 3D (horizontal and height) or time. More in details:

- **Horizontal position accuracy** is the statistical measure of the horizontal position (or velocity) error (e.g. 95th percentiles of the cumulative error distribution), being this error the difference between the true horizontal position and the position (or velocity) estimated by a positioning system at a given time. The requirements for this feature can range from relaxed constraints for personal navigation applications, to more stringent ones for LCA such as road user charging and tracking of dangerous goods.
- **Vertical position accuracy** is the statistical measure of the vertical position error (e.g. 95th percentiles of the cumulative error distribution), being this error the difference between the true vertical position and the position estimated by a positioning system at a given time. This feature applies when vertical guidance is required, for instance to allow proper positioning in case of parkade (multi-levels parking) or overlapping road segments, especially in urban environments.

- **GNSS time accuracy** is the statistical measure of the GNSS time error (e.g. 95th percentiles of the cumulative error distribution), being this error the difference between the true GNSS time (as implemented in the GNSS system timing facility) and the time returned by the positioning system based on the PVT solution. Generally, this feature is of interest for applications requiring synchronisation of assets distributed across wide geographical areas, where GNSS time is used as a reference. Focusing on the road segment, GNSS time accuracy applies for example in case on VANET applications (involving a very large number of distributed nodes) that in future might require the use of synchronous Medium Access Control (MAC) in order to overcome the known scalability issue of the decentralized and asynchronous Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) method.

Continuity: ability to provide the required performance during an operation without interruption once the operation has started. Continuity is usually expressed as the risk of a discontinuity and depends entirely on the timeframe of the application (e.g. an application that requires 10 minutes of uninterrupted service has a different continuity figure than one requiring two hours of uninterrupted service, even if using the same receiver and services). A typical value is 1x10-4 over the course of the procedure where the system is in use.

Integrity: the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver. This is usually expressed as the probability of a user being exposed to an error larger than alert limits without warning. The way integrity is ensured and assessed, and the means of delivering integrity related information to the user are highly application dependent. For safety-of-life-critical applications such as passenger transportation, the "integrity concept" is generally mature, and integrity can be described by a set of precisely defined and measurable parameters. This is particularly true for civil aviation. For less critical or emerging applications, however, the situation is different, with an acknowledged need of integrity but no unified way of quantifying or satisfying it. Throughout this report, "integrity" is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used by other applications and sectors. In road applications, it is relevant to SCA and LCA (e.g. critical navigation, billing).

Robustness to spoofing and jamming: robustness is a qualitative, rather than quantitative, parameter that depends on the type of attack or interference the receiver is capable of mitigating. It can include authentication information to ensure users that the signal comes from a valid source (enabling sensitive applications).

Note: for some users robustness may have a different meaning, such as the ability of the solution to respond following a severe shadowing event. For the purpose of this document, robustness is defined as the ability of the solution to mitigate interference or spoofing. Within robustness:

- **Position authenticity** gives a level of assurance that the data provided by a positioning system has been derived from real signals. Radio frequency spoofing may affect the positioning system resulting in false position data as output of the system itself.
- **Robustness to interference** is the ability of the positioning system to operate under interference conditions and to maintain the applicable positioning service level requirements. Location Systems might be required to operate in constrained RF environments, in particular in the GNSS frequency bands. Note that interference can be either unintentional or deliberate (e.g. jamming).

Indoor penetration: ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS, this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of Wi-Fi base stations for Wi-Fi-based positioning).

Time To First Fix (TTFF): a measure of a receiver's performance covering the time between activation and output of a position within the required accuracy bounds. Activation means subtly different things depending on the status of the data the receiver has access to:

- **Cold start:** the receiver has no knowledge of the current situation and thus has to systematically search for and identify signals before processing them – a process that typically takes 15 minutes.
- **Warm start:** the receiver has estimates of the current situation – typically taking 45 seconds.
- **Hot start:** the receiver knows what the current situation is – typically taking 20 seconds.

This feature is of particular interest for the navigation support (route guidance) of emergency vehicles, provided that the positioning system in the emergency vehicle has to be prompt to accurately estimate its position.

Latency: the difference between the time the receiver estimates the position and the presentation of the position solution to the end user (i.e. the time taken to process a solution). Latency is usually not considered in positioning, as many applications operate in, effectively, real time. However, it is an important driver in the development of receivers. This is typically accounted for in a receiver, but is a potential problem for integration (fusion) of multiple positioning solutions or for high dynamics mobiles. In the context addressed in this document, the PVT latency may matter in two families of cases:

- **GNSS latency:** the first case is the integration of GNSS measurements with other higher-rate sensors, in which a latency in the provision of the PVT-related measurements by the GNSS sensor may encompasses several adjacent measurements of the higher-rate sensor, imposing the need for a non-trivial re- synchronization. This case might be significant for autonomous driving applications, in which high-rate sensors readings may be a safety factor.
- **PVT latency** (from the positioning terminal): the second case represents the situation in which the PVT solution provided by positioning terminal to the application interface is delayed by a certain amount of time with respect to the nominal instant of the measurements, due to the amount of processing performed by the PVT determination function. PVT latency may become non- negligible in case of complex integration processing, or latencies in data retrieval from the sensors or from other external sources (e.g., PPP corrections from the internet).

Power consumption: the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GPS chips will use more power when scanning to identify signals (cold start) than when computing position. Typical values are in the order of tens of mW (for smartphone chipsets).

GNSS sensitivity refers to the minimum GNSS signal strength at the antenna, detectable by the receiver (dBW or dBm). The GNSS sensitivity is a relevant feature in all the applications involving possible urban and light indoor scenarios (especially eCall and emergency services).

Position fix rate It is the rate at which the positioning terminal outputs the PVT data. This is not independent from the PVT update rate of the GNSS receiver, for which the typical rate is 1 Hz. Consequently, the distance between two positions if the vehicle drives at 90Km/h, would be 25 meters. Nonetheless some positioning architectures (e.g.: GNSS receiver coupled with inertial sensors) might require higher output rates from the GNSS receiver. For certain automotive application like collision avoidance or red-light violation warning the fix rate should be 10 Hz or more.

ANNEX 3: LIST OF ACRONYMS

ADAS	Advanced Driver Assistance Systems
ADS	Autonomous Driving Systems
EGNOS	European Geostationary Navigation Overlay System
EGNSS	European GNSS
ERTRAC	European Road Transport Research Advisory Council
ETP	European Technology Platform
ETSC	European Transport Safety Council
EU	European Union
EV	Electric Vehicle
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSA	European GNSS Agency
HA	High Accuracy
IAG	International Association of Geodesy
ICD	Interface Control Document
ISO	International organisation for Standardisation
ITS	Intelligent Transport System
LCA	Liability Critical Applications
LSVA	Large Scale Video Analysis
MaaS	Mobility-as-a-Service
MOC	Medium Access Control
OADF	Open AutoDrive Forum
OEM	Original Equipment Manufacturer
ORAD	On-Road Automated Driving
OS NMA	Open Service Navigation Message Authentication
PNT	Position, Navigation and Timing
PPP	Precise Point Positioning
PVT	Position Velocity Time
SAE	Society of Automotive Engineers
SCA	Safety Critical Applications
SCSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
TTFF	Time To First Fix
UCP	User Consultation Platform
V2X	Vehicle to Everything communication

www.euspa.europa.eu

EU4Space

EU4Space

EUSPA

EUSPA

Space4EU